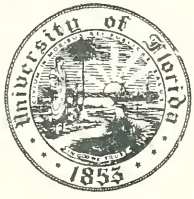
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A Complete Alphabetical Index
to All Sections

FIRST EDITION

Published by the
ILLUMINATING ENGINEERING SOCIETY
51 MADISON AVENUE, NEW YORK 10, N. Y.
1947

ARCHI-
TECTURE
BOOK ROOM

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COMPOSED AND PRINTED
BY
THE WAVERLY PRESS
BALTIMORE, MARYLAND
1947

PREFACE

Through the years since 1906, the Illuminating Engineering Society has been publishing the findings of the leaders in the fields of lighting application and research. In addition to the 41 volumes of its journal, the I.E.S. Film, and the many lighting installation data sheets, pamphlets and books prepared under its sponsorship, there is today so much excellent literature on lighting published by others that it has become exceedingly difficult to keep abreast of advancement along the ever-expanding lighting horizon. For one person to collect and digest the findings of the past half-century of progress would require a life-time of research. Nevertheless, an understanding of the basic technical information and of time-tested application techniques is recognized as the best foundation for further advancement. It is conceived by the Society that this Handbook will provide its readers with the essential information required in their daily work.

In simple terms and highly condensed style the IES Lighting Handbook places conveniently within reach of all its readers the accumulated knowledge of the past forty-one years of lighting progress, evaluated and interpreted with respect to today's needs by a highly qualified group of over 100 contributing specialists—engineers, architects, physicists, decorators, artists and opthalmologists—who have worked for more than two years under the direction of a special committee of the Society and a full-time editorial staff to provide the most complete coverage of the field possible within the limits of a conveniently-sized volume.

In many ways the IES Lighting Handbook is particularly well-adapted to reader convenience. For example, the type face is larger than that often encountered in engineering handbooks and, in combination with the mat finish paper, is more legible. To make clear and easily understood all points of particular importance, an unusually large number of carefully selected photographs and specially prepared line drawings are included.

The detailed alphabetical index provides a simple means of finding discussion on subjects of interest, and the original literature referenced at the end of each section will amplify the condensed handbook treatment.

To aid in completing lighting installation plans, detailed data on many types of commercially available lighting equipment are included in the *Manufacturers' Data Section.*

In some instances, as in the case of the *Average Brightness Calculation Procedure,* formerly thought to be a complex tool of the mathematician, it has been possible, for the first time, to simplify design techniques, and other working tools, so that now they may be used easily by everyone.

Every precaution has been taken to secure broad coverage of all phases of lighting and a completely objective approach. First, the integrated views of several different specialists were incorporated in each section of the manuscript and, finally, the printer's proof was read and approved by a Board of Review including the President and several Past Presidents of the Illuminating Engineering Society.

12-9-48 — Illuminating Eng. Soc. — Architecture

We wish to acknowledge with sincere appreciation the assistance of the many individuals who cooperated in the preparation of the manuscript. The following list of names of the contributors cannot reveal the hours of effort which they devoted to the work. Each deserves a large portion of credit for the completion of a difficult assignment.

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The part played by the IES Lighting Handbook Committee and by its Board of Review was most important. These men contributed their best thinking and experience both before and after the production of manuscript had begun, and during the reading of proof, in establishing the basic policies which are revealed in the completely practical character of this first edition. Their critical appraisal and check of the manuscript after its preparation added much to its overall utility as well as to its technical accuracy.

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The preparation and publication of the Handbook proceeded under the administration of the following Presidents of the Illuminating Engineering Society:

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The General Office Staff took an active part in many phases of the work under the direction of A. D. Hinckley, *Handbook Business Manager* and *Executive Secretary* of the Society. C. L. Crouch, the Society's *Technical Director*, acted as Handbook Editor during the formative stages of the project and made many investigations upon which the plans for publication were based.

Recognizing that much remains to be learned about light and its applications, we feel, nevertheless, that this first edition will faithfully serve its readers. It is inevitable in a book of this size that some errors and omissions will be discovered. Your cooperation in calling them to our attention will be appreciated.

Robert W. McKinley
EDITOR

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So many excellent photographs were contributed that only a small portion of the total could be included in the Handbook. The availability of the larger number made possible the establishment of the highest standards for the final selection.

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SECTION 1

THE PHYSICS OF LIGHT PRODUCTION

The American Standards Association and the Illuminating Engineering Society define light as *radiant energy evaluated according to its capacity to produce visual sensation.* Radiant energy of the proper wavelength makes visible anything from which it is emitted or reflected in sufficient quantity to activate the receptors in the eye.

Several concepts of the nature of radiant energy have been advanced.[1] They are:

A. The *corpuscular theory* advocated by Newton, based on these premises:
1. That luminous bodies emit radiant energy in particles.
2. That these particles are intermittently ejected in straight lines.
3. That the particles act on the retina of the eye stimulating the optic nerves to produce the sensation of light.

B. The *wave theory*, based on these premises:
1. That light is the resultant of molecular vibration in the luminous material.
2. That vibrations are transmitted through the ether as wavelike movements (comparable to ripples in water).
3. That the vibrations thus transmitted act on the retina of the eye stimulating the optic nerves to produce visual sensation.

C. The *electromagnetic theory*,[2] based on these premises:
1. That luminous bodies emit light as a form of radiant energy.
2. That this radiant energy is transmitted in the form of electromagnetic waves.
3. That the electromagnetic waves act upon the retina of the eye thus stimulating the optic nerves to produce the sensation of light.

D. The *quantum theory*, a modern form of the corpuscular theory, based on these premises:
1. That energy is emitted and absorbed in discrete quanta.
2. That the magnitude of each quantum is $h\nu$,
where $h = 6.547 \times 10^{-27}$ erg sec (Planck's constant)
and ν = frequency in cycles per second.

E. The *theory of wave mechanics* first proposed by Schrödinger in 1925 in an attempt to reach an harmonious compromise between the quantum and the wave theories.
1. It utilizes wave characteristics and quanta particles as the need arises in the solution of problems.
2. The mathematics involved is too complicated for present application to illuminating engineering problems.

NOTE: References are listed at the end of each section.

Until such time as new data or concepts are available the quantum and the electromagnetic wave theories will unquestionably be used as the basis of continued research in light phenomena. The electromagnetic wave theory provides a convenient explanation of those characteristics of radiant energy most frequently of concern to the illuminating engineer.

Radiant energy may be evaluated in a number of different ways; two of these are:

1. *Radiant flux*—the time rate of the flow of any part of the radiant energy spectrum *measured in ergs per second.*

2. *Luminous flux*—the time rate of the flow of the luminous parts of the radiant energy spectrum *measured in lumens.*

Light and the Energy Spectrum

The wave theory permits a convenient graphical representation of radiant energy in an orderly arrangement according to its wavelength. This arrangement is called a spectrum (Fig. 1-1). It is useful in indicating the relationship between various radiant energy wavelength regions. Such a graphical representation must not be construed to indicate that each region of the spectrum is divided from the others in any physical way whatsoever. Actually there is a gradual transition from one region to another.

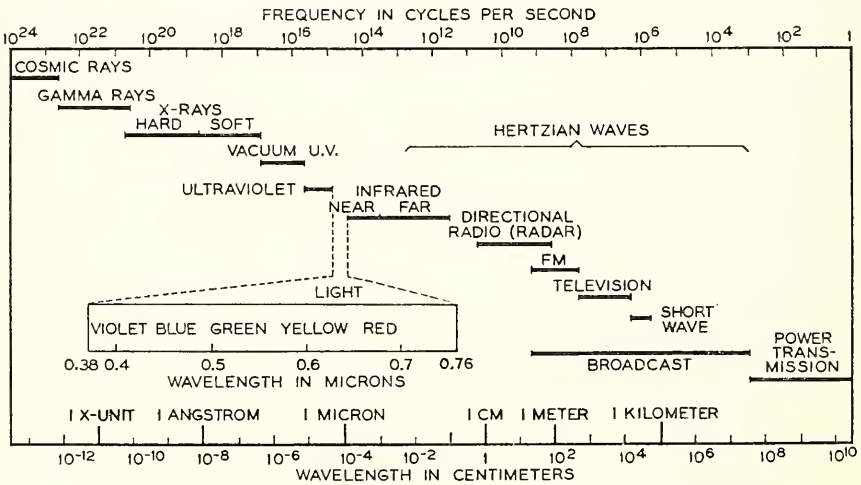


FIG. 1-1. The radiant energy (electromagnetic) spectrum.

The known limits of the radiant energy spectrum extend over a range of wavelengths varying from a few micromicrons (10^{-10} cm) to one hundred thousand miles (1.6×10^{10} cm). Radiant energy in the visible spectrum has wavelengths between 0.38×10^{-4} and 0.76×10^{-4} cm.

The Angstrom unit (A), the micron (μ), and the millimicron ($m\mu$) are commonly used units of length in the visible spectrum band. The relationship of several units for measuring wavelength is given in Table 1-1.

All forms of radiant energy are transmitted at the same rate of speed in vacuum (186,300 miles per second). However, each form differs in wavelength and thus in frequency. The wavelength and velocity may be altered materially by the medium through which it passes, but frequency is fixed independently of the medium. Thus, through the equation:

$$V = n\lambda\nu$$

where V = velocity of waves (cm per sec)
n = (index of refraction)
λ = wavelength (cm)
ν = frequency (c per sec)

it is possible to determine the velocity of radiant energy and also to indicate the relationship between frequency and wavelength.

Table 1-2 gives the velocity of light in different media for a frequency corresponding to a wavelength of 0.589 micron in air.

Table 1-1. Conversion Table for Units of Length

Multiply Number of → / By / To Obtain Number of ↓	ANGSTROMS	MICRONS	MILS	INCHES	FEET	MILES	MILLIMETERS	CENTIMETERS	KILOMETERS
ANGSTROMS	1	10^{4}	2.540×10^{5}	2.540×10^{8}	3.048×10^{9}	1.609×10^{13}	10^{7}	10^{8}	10^{13}
MICRONS	10^{-4}	1	2.540×10	2.540×10^{4}	3.048×10^{5}	1.609×10^{9}	10^{3}	10^{4}	10^{9}
MILS	3.937×10^{-6}	3.937×10^{-2}	1	10^{3}	1.2×10^{4}	6.336×10^{7}	3.937×10	3.937×10^{2}	3.937×10^{7}
INCHES	3.937×10^{-9}	3.937×10^{-5}	10^{-3}	1	12	6.336×10^{4}	3.937×10^{-2}	3.937×10^{-1}	3.937×10^{4}
FEET	3.281×10^{-10}	3.281×10^{-6}	8.333×10^{-5}	8.333×10^{-2}	1	5.280×10^{3}	3.281×10^{-3}	3.281×10^{-2}	3.281×10^{3}
MILES	6.214×10^{-14}	6.214×10^{-10}	1.578×10^{-8}	1.578×10^{-5}	1.894×10^{-4}	1	6.214×10^{-7}	6.214×10^{-6}	6.214×10^{-1}
MILLIMETERS	10^{-7}	10^{-3}	2.540×10^{-2}	2.540×10	3.048×10^{2}	1.609×10^{6}	1	10	10^{6}
CENTIMETERS	10^{-8}	10^{-4}	2.540×10^{-3}	2.540	3.048×10	1.609×10^{5}	0.1	1	10^{5}
KILOMETERS	10^{-13}	10^{-9}	2.540×10^{-8}	2.540×10^{-5}	3.048×10^{-4}	1.609	10^{-6}	10^{-5}	1

Table 1-2. Velocity of Light for a Wavelength of 0.589 Micron
(Sodium D-lines)

MEDIUM	VACUUM	AIR (760 mm 0°C)	CROWN GLASS	WATER
VELOCITY (cm per sec)	$(2.99776 \pm 0.00004) \times 10^{10}$	2.99708×10^{10}	1.98212×10^{10}	2.24903×10^{10}

Luminosity of Radiant Energy

The apparent differences in character between radiant energy of various wavelengths are in reality differences in ability of various receiving and detecting devices.[3]

The *reception characteristics of the human eye* have been subject to extensive investigations. The results may be summarized as follows:

1. The spectral response characteristic of the human eye varies between individuals, with time, and with the age and the state of health of any individual, to the extent that the selection of any individual to act as a *standard observer* is not scientifically feasible.

2. However, from the wealth of data available, a luminosity curve has been selected for engineering purposes which represents the average human observer. This curve may be applied mathematically to the solution of photometric problems so as to eliminate the disadvantages related to all measurements dependent on the accurate reporting of human sensations. (See also Section 2.)

Recognizing these facts, the Illuminating Engineering Society in 1923 and the International Commission on Illumination (I.C.I.) in 1924 adopted the standard luminosity factors of Table 1-3 from which the luminosity curve of Fig. 1-2 was plotted.

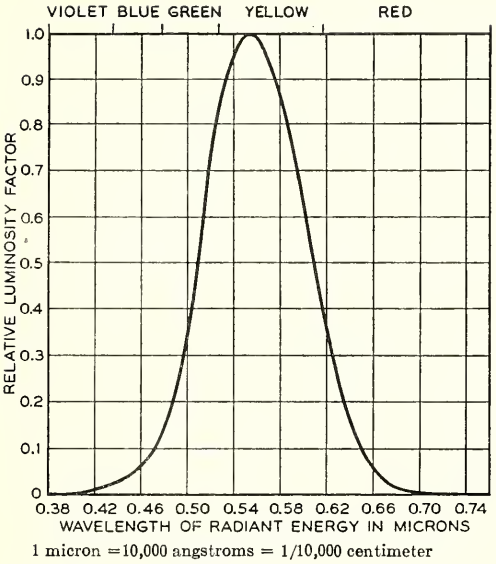
Table 1-3. Standard Luminosity Factors

(Relative to unity at 0.554 micron wavelength)*

WAVELENGTH (micron)	FACTOR	WAVELENGTH (micron)	FACTOR	WAVELENGTH (micron)	FACTOR
0.380	0.00004	0.510	0.503	0.640	0.175
.390	.00012	.520	.710	.650	.107
.400	.0004	.530	.862	.660	.061
.410	.0012	.540	.954	.670	.032
.420	.0040	.550	.995	.680	.017
.430	.0116	.560	.995	.690	.0082
.440	.023	.570	.952	.700	.0041
.450	.038	.580	.870	.710	.0021
.460	.060	.590	.757	.720	.00105
.470	.091	.600	.631	.730	.00052
.480	.139	.610	.503	.740	.00025
.490	.208	.620	.381	.750	.00012
.500	.323	.630	.265	.760	.00006

* Luminosity factor = 1.0002 for 0.555 micron is maximum.

The standard luminosity curve represents an average characteristic from which the characteristic of any individual may be expected to vary. Goodeve's data (Fig. 1-3) indicate that most human observers are capable of experiencing a visual sensation upon exposure to radiation of infrared wavelengths (longer than 0.76 micron). It also is known that observers exhibit a slight response to ultraviolet wavelengths (shorter than 0.38 micron).



1 micron =10,000 angstroms = 1/10,000 centimeter

FIG. 1-2. The standard (I.C.I.) luminosity curve shows the relative capacity of radiant energy of various wavelengths to produce visual sensation.

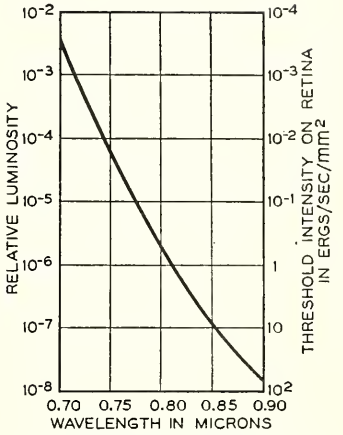


FIG. 1-3. Goodeve's investigations reveal that high flux concentrations of wavelengths just outside the "visible region" are capable of producing visual sensations.[7]

Photoelectric Effect

This phenomenon, which may be observed when a clean metal surface is illuminated, is the liberation of electrons from the surface atoms. If the surface is connected as a cathode in an electric field (Fig. 1–4) the liberated electrons will flow to the anode creating a photoelectric current. An arrangement of this sort may be used as an illumination meter and can be calibrated in footcandles.

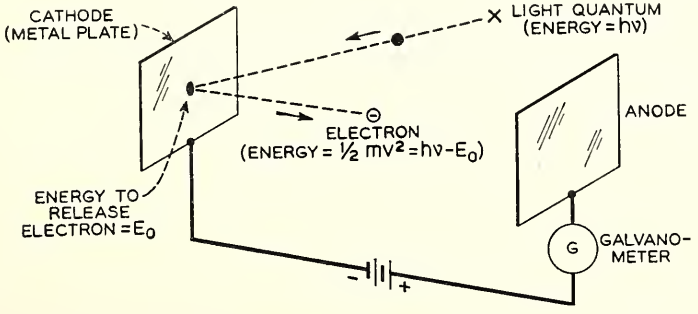


FIG. 1-4. By the photoelectric effect, electrons may be liberated from illuminated metal surfaces. In an electric field these will flow to an anode and create an electric current which may be detected by means of a galvanometer.

Effect of illumination. It has been found that the photoelectric current in vacuum varies directly with the illumination over a very wide range (spectral distribution, polarization, and cathode potential remaining the same). In gas-filled tubes the response is linear over only a limited range.

Effect of polarization. If the illumination is polarized, the photoelectric current will vary as the orientation of the polarization is changed (except at normal incidence).

Effect of wavelength. The more electropositive the metal the longer the wavelength of its maximum photoelectric emission and the lower the frequency threshold below which electrons are not liberated. (See Table 1–4.)

Table 1-4. The Electrode Potential Series

Li	Rb	K	Cs	Na	Ba	Sr	Ca	Mg	Mn	Zn	Cr	Fe*	Cd	Tl	Co	Ni	Sn	Pb	Fe†	Sb	Bi	As	Cu	Ti	Pt	Hg	Ag	Au
HIGH																												LOW

* ferrous † ferric

The maximum value of the initial velocity of a photoelectron and therefore its maximum kinetic energy decrease as the wavelength of the illumination increases.

The quantum theory provides the energy relationships which explain this phenomenon. The energy E of a light quantum equals the product of Planck's constant h by the frequency ν:

$$E = h\nu$$

It is known that an amount of energy E_0 (different for each metal) is required to separate an electron from the atom with which it is associated.

Therefore, the energy of the liberated electron ($\frac{1}{2}mv^2$) is equal to that of the incident quantum $h\nu$ less E_0, that required to free it from the metal:

$$\frac{1}{2}mv^2 = h\nu - E_0$$

where m = mass of electron

v = velocity of electron

The *barrier layer or photovoltaic cell*, when illuminated, generates voltage even though not connected to an external power source. The cell comprises a metal plate coated with a semiconductor (selenium on iron or cuprous oxide on copper, for example). Upon exposure to light, electrons liberated from the metal surface are trapped at the interface unless there is an external circuit provided through which they may escape. In photographic and illumination meters, this circuit includes a small microammeter calibrated in units of illumination. (See Fig. 1-5.) This type is commonly used in photographic exposure meters and portable illumination meters.

Light Production

Light may be produced in many ways and by several types of devices tabulated under two broad headings:

1. Incandescence
 - Combustion
 - Arc electrodes
 - Gas mantle
 - Lamp filament
 - Radiant heater
2. Luminescence
 - Arc stream
 - Gaseous discharge
 - Glow discharge
 - Fluorescence
 - Phosphorescence
 - Cathodoluminescence
 - Chemiluminescence
 - Triboluminescence

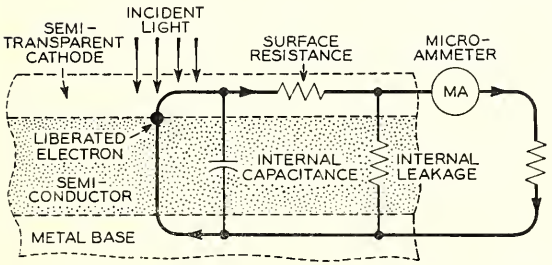


FIG. 1-5. Cross section of barrier layer or photovoltaic cell showing motions of photoelectrons through microammeter circuit.

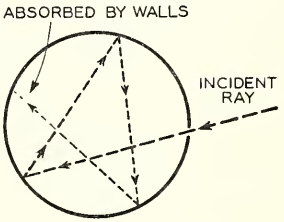


FIG. 1-6. Small aperture in an enclosure exhibits blackbody characteristics.

The physical phenomena associated with light production by these means are best explained by Planck's quantum theory and by the modern atomic theories first conceived by Bohr and Rutherford.

Incandescence

Familiar physical objects are simple or complex combinations of chemically identifiable molecules, which in turn are made up of atoms. In solid materials the molecules are packed together and the substances hold their shape almost indefinitely over a wide range of physical conditions. In contrast, the molecules of a gas are highly mobile and occupy only a small part of the space filled by the gas.

Single molecules and atoms are much too small (3×10^{-8} cm) to be observed directly, but much is known of their characteristics.

Molecules of both gases and solids are constantly in motion and their movement is a function of temperature. If the solid or gas is hot, the molecules move rapidly; if it is cold, they move more slowly.

At temperatures below about 573 degrees Kelvin (300 degrees Centigrade) invisible energy of the longer infrared (*heat*) wavelengths is emitted

by any body, a coal stove or an electric iron, for example. The jostling of the molecules at temperatures above 300 degrees Centigrade results in the release of visible radiation along with the heat. Molecular activity in the filament, caused by the heating action of the electric current, results in the production of light by the incandescent electric lamp.

Blackbody Radiation

The light from practical light sources, particularly that from incandescent lamps, is often described by comparison with that from a blackbody or complete radiator. Defined as a *body which absorbs all of the radiation incident upon it, transmitting none and reflecting none*, a blackbody will for equal area radiate more *total* power and more *power at any given wavelength* than any other source operating at the same temperature, unless that source radiates energy by some phenomenon other than temperature.

For experimental purposes, laboratory sources have been devised which approach the ideal blackbody very closely in output characteristics. All of the many different designs are based on the fact that a hole in the wall of a closed chamber, small in size as compared with the size of the enclosure, is absolutely black. This is understood if one considers what happens to a ray of light entering such an enclosure. (See Fig. 1-6.) Assuming the reflectance of the walls to be low, the incident energy soon will be absorbed in the walls by interreflections.

Recently the brightness of a blackbody operating at the temperature of freezing platinum has been established as a new international candlepower reference standard. It has the advantage of reproducibility over the bank of carbon filament lamps which have been in use for so many years. (See footnote on page 1–12, also Section 3.)

Planck's equation for blackbody radiation was developed, by the introduction of the concept of radiation of discrete quanta of energy, to represent the radiation curves obtained in 1900 by Lummer and Pringsheim, who used the open end of a specially constructed and uniformly heated tube as their source. It has the form:

$$W_\lambda = c_1\lambda^{-5}(e^{c_2/\lambda T} - 1)^{-1}$$

where W_λ = watts radiated by a blackbody (per cm² of surface) in each wavelength band one micron wide, at wavelength λ

λ = wavelength in microns (μ)

T = absolute temperature of the blackbody (degree Kelvin)

c_1 = 36,970*

c_2 = 14,320*

e = 2.718+

* Improvements made by various investigators in the techniques by which these constants are determined result in the publication, from time to time, of slightly different values.

The following values, which have been used in calculations of the maximum luminous efficiency of radiant energy accepted by the I. E. S., were published in 1939 by H. T. Wensel in the Journal of Research of the National Bureau of Standards:

$c_1 = 3.732 \times 10^{-5}$ erg cm² second^{-1}

$c_2 = 1.436$ cm degree

$\sigma = 5.70 \times 10^{-5}$ erg cm^{-2} degree^{-4} second^{-1}

(See footnote page 1-12)

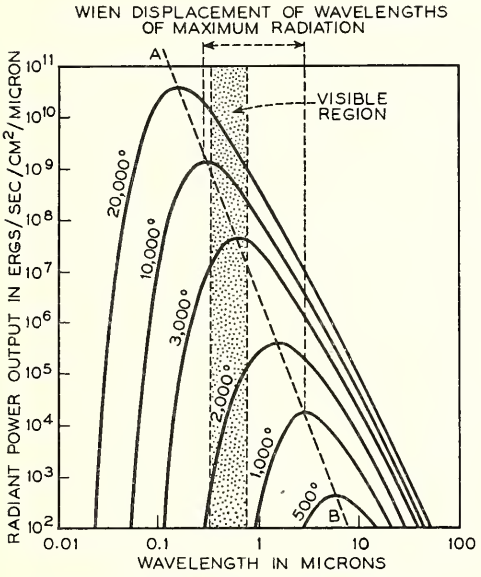
The most recent values, published in 1941 by R. T. Birge in Reviews of Modern Physics, are:

$c_1 = 3.738 \times 10^{-5}$ erg cm² second^{-1}

$c_2 = 1.438_{48}$ cm degree

$\sigma = 5.672_{33} \times 10^{-5}$ erg cm^{-2} degree^{-4} second^{-1}

The curves for several values of T are plotted on a logarithm scale in Fig. 1-7.



1 micron = 10,000 angstroms = 1/10,000 centimeter

FIG. 1-7. Blackbody radiation curves for operating temperatures between 500 degrees Kelvin and 20,000 degrees Kelvin showing Wien displacement of peaks. Shaded area is region of visible wavelengths.

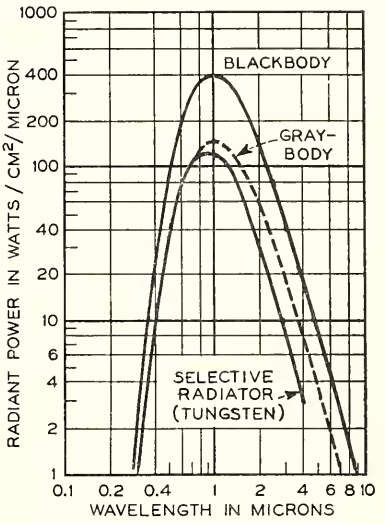


FIG. 1-8. Radiation curves for blackbody, graybody, and selective radiators operating at 3,000 degrees Kelvin.

Wien radiation law. In the temperature range of tungsten filament lamps (2,000 degrees Kelvin–3,400 degrees Kelvin) and in the visible wavelength region (0.38–0.76μ), the following simplification of the Planck equation known as the Wien radiation law gives a reasonably accurate representation of the blackbody distribution:

$$W_\lambda = c_1\lambda^{-5}e^{-c_2/\lambda T}$$

The *Wien displacement law* gives the relation between blackbody distributions for various temperatures (see line AB, Fig. 1-7):

$$W_\lambda = c_1\lambda^{-5}F(\lambda T)$$

where F = luminous flux (lumens) the principal corollaries are:

$$\lambda_{\max}T = b \text{ (2883.6 micron-degrees)}$$

where $\lambda_{\max}$ is the wavelength, in microns, at which blackbody radiation is a maximum, found by setting $\dfrac{dW}{d\lambda} = 0$.

$$W_{max}T^{-5} = b_1 = 1.3 \times 10^{-11} \text{ watt cm}^{-3} \text{ degree}^{-5}$$

The *Stefan-Boltzmann law,* obtained by integrating Planck's expression for W_λ from zero to infinity, states that the *total radiant power* per unit area of a blackbody varies as the fourth power of the absolute temperature:

$$W = \sigma T^4 \text{ watts per cm}^2$$

where W = summation of power per unit area radiated by a blackbody at all wavelengths
σ = 5.735×10^{-12} watt cm^{-2} degree^{-4} (see footnote, page 1–8)
T = temperature of the radiator (degree Kelvin)

It should be noted that this equation applies to the total power, that is, the whole spectrum. It cannot be used to estimate the power in the visible portion of the spectrum alone.

Graybody Radiation

A radiator which does not emit as much power as a blackbody but which has exactly the same spectral distribution is known as a graybody.

The ratio of its output at any wavelength to that of a blackbody at the same wavelength is known as the *spectral emissivity* (e_λ) of a radiator. No known radiator has a constant spectral emissivity for all visible, infrared, and ultraviolet wavelengths, but in the visible region a carbon filament exhibits very nearly uniform emissivity, that is, is nearly a graybody.

Selective Radiators

The emissivity of all known materials varies with wavelength. Therefore, they are called selective radiators.

Drude equation. Values of spectral emissivity e_λ at wavelengths greater than 2 microns may be calculated with reasonable accuracy by means of the Drude equation:

$$e_\lambda = 0.365\sqrt{\frac{\rho}{\lambda}}$$

where ρ = the electrical resistivity of the emitting material (ohm-cm)
λ = wavelength (cm)

For shorter wavelengths, at which the resistivity is a function of the frequency of the emitted wavelengths, the Drude equation does not give good results and the emissivity must be determined experimentally.

Blackbody, graybody, and selective radiator comparison. In Fig. 1-8 the radiation curves for a blackbody, a graybody, and a selective radiator (tungsten), all operating at 3,000 degrees Kelvin, are plotted on the same logarithm scale to show the characteristic differences in output.

Radiation equations into which the spectral emissivity factor has been introduced are applicable to any incandescent source:

Planck's equation: $W_\lambda = 36{,}970\, e_\lambda \lambda^{-5}(10^{6219.10/\lambda T} - 1)^{-1}$ (See footnote, page 1-8)

Wien radiation law: $W_\lambda = 36{,}970\, e_\lambda \lambda^{-5}\, 10^{-6219.10/\lambda T}$

Stefan-Boltzmann law: $W = 5.735 \times 10^{-12} e_t\, T^4$

$$\text{where } e_t = \frac{\int_0^\infty e_\lambda W_\lambda \, d\lambda}{\int_0^\infty W_\lambda \, d\lambda} \text{ (total emissivity)}$$

The *arc lamp* radiates both because of the incandescence of the anode and by the luminescence of vaporized electrode material in the arc stream. By varying the electrode materials considerable spread in the spectral distribution and high brightness may be achieved.

Color Temperature

The radiation characteristics of a blackbody of unknown area may be specified with the aid of the equations on page 1-8 by fixing only two quantities: the magnitude of the radiation at any given wavelength and the absolute temperature. The same type of specification may be used with reasonable accuracy for tungsten filaments and other incandescent sources. However, the temperature used in the case of selective radiators is not that of the filament but a value called the color temperature.

The *color temperature* of a selective radiator is equal to that temperature at which a blackbody must be operated if its output is to be the closest possible approximation to a perfect color match of the output of the selective radiator. (See also Section 4.) While the match is never absolutely perfect the small deviations which occur in the case of incandescent lamps are not of practical importance.

The apertures between coils of the filaments used in many tungsten lamps act somewhat as a blackbody because of the interreflections which occur at the inner surfaces of the helix formed by the coil. For this reason the distribution from coiled filaments exhibits a combination of the characteristics of the straight filament and of a blackbody operating at the same temperature.

The application of the color temperature specification to luminescent rather than incandescent sources may result in appreciable errors.

Efficiency

The efficiency of a device with respect to the storage, transfer, or transformation of a physical quantity is defined for most engineering purposes as the ratio of the useful output of the quantity to its total input, the output and input usually being expressed in units of power.

The *efficiency of a light source* is defined as the ratio of the total luminous flux (lumens) to the total power input (watts or equivalent).

Effect of spectral distribution. Since most of the energy radiated by incandescent sources is of the long invisible infrared wavelengths, the achievable efficiencies are low as compared with the theoretical maximum (650 lumens per watt) that would be obtained if all of the power input were emitted as green light of 0.5550 micron wavelength for which the luminosity factor is greatest.*

Because of the shift with increases in temperature from the infrared to shorter wavelengths of the maximum of the radiation curve, efficiency may be increased by operating lamps at higher temperatures.

Effect of material characteristics. In practical lamps the rate of evaporation and the melting point of the filament limit the extent of such gains. The melting point of tungsten is 3,655 degrees Kelvin, the highest of all metallic elements.

Because evaporation of the filament at temperatures approaching the melting point is great enough to cause unreasonably short life and much bulb blackening, it is necessary to operate practical lamp filaments at temperatures well below the melting point. However, even if it were possible to go much higher than known filament materials allow, the efficiency would not greatly exceed the maximum of 85 lumens per watt achievable with blackbody radiators operating at the optimum temperature of about 6,500 degrees Kelvin, because much of the energy is radiated outside the visible region.

The *maximum attainable efficiency* of any white light source (whether it be a blackbody, tungsten, gaseous discharge, or fluorescent type) *with its entire output distributed uniformly with respect to wavelength within the visible region*, is of the order of 200 lumens per watt.

Efficiencies greater than 200 lumens per watt can be obtained but only from sources of which the entire output approaches concentration in the green wavelength of the maximum luminosity factor.

Maximum attainable brightness. From a superficial consideration of the matter it may appear that the brightness of an illuminated surface might be raised to any desired value merely by concentrating light upon it from a sufficient number of sources. The fact remains that the attainable brightness is limited by the attainable brightness of the available light sources.

The top limit depends on the optical arrangement. If the arrangement does not return significant amounts of radiation to the sources, the maximum brightness attainable will be that of the sources. If radiation is returned to the sources, the top limit will approach the brightness of a blackbody operating at the true temperature of the sources.

Luminescence

Whereas the radiation of incandescent sources results from the irregular excitation at high temperatures of innumerable molecules interacting on

* The value adopted by the I.E.S. (650 lumens per watt) is based on: 1. the 1924 I.C.I. luminosity factors; 2. the second radiation constant in Planck's equations $c_2 = 1.436$; and 3. the brightness of a blackbody at the freezing point of platinum (58.9 candles per square centimeter). It is consistant with the calculations of H.T. Wensel published in 1939 ("Research Paper 1189" *J. Research Nat. Bur. Stand.*). See note page 1-8.

each other and is emitted in all wavelengths to form a continuous spectrum, radiation from luminescent sources results primarily from the excitation of individual atoms so scattered or arranged that each atom is free to act without much interference from its neighbors.

Radiation resulting from the excitation of the electrons of an atom will be emitted at one of the series of wavelengths characteristic of that particular element.

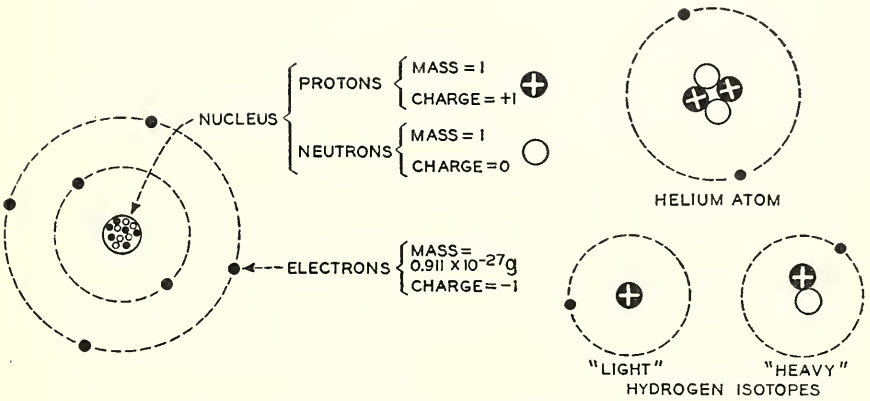


FIG. 1-9. Structure of the atom showing electron orbits around central nucleus Hydrogen isotopes and helium atom are simplest of all atomic structures.

Atomic Structure

The atomic theories first proposed by Rutherford and Bohr in 1913 have since been expanded upon and verified repeatedly by careful experiment. They propose that each atom is in reality a minute solar system, such as that shown in Fig. 1-9.

The *atom* consists of a central nucleus possessing a positive charge n about which rotate n negatively charged electrons. In the normal state these electrons remain in particular orbits or energy levels and radiation is not emitted by the atom.

The *nucleus* is made up of protons that carry the positive charge and neutrons that are approximately equal in mass to the protons but uncharged.

The number of protons in the nucleus is always the same for a given element and gives that element its atomic number.

All the atoms of a given element have the number of protons in the nucleus equal to the atomic number Z; but they may differ in the number of neutrons $A-Z$. Atomic species so differing are called isotopes, as in the case of deuterium or "heavy" hydrogen (Fig. 1-9), which has a neutron in its nucleus in addition to the single proton of "light" hydrogen. Similarly, the isotopes U-234, U-235, and U-238 of uranium contain 92 protons each but 142, 143, and 146 neutrons respectively.

The *system of orbits or energy levels* in which the electrons are pictured rotating about the nucleus is characteristic of each element and remains stable until disturbed by external excitation.

Chemical reactions between the elements involve only the valence electrons in the outer orbits.

Light production. It is by the proper excitation of the valence electrons that visible radiation is produced in luminescence phenomena.

The Carbon Arc

Low-intensity arcs. Of the three principal types of carbon arc in commercial use, the low-intensity arc is the simplest. In this arc, the light source is the white-hot tip of the positive carbon. This tip is heated to a temperature near its sublimation point (3,700 degrees Centigrade) by the concentration of a large part of the electrical energy of the discharge in a narrow region close to the anode surface. (See Fig. 1-10.)

The gas in the main part of the arc stream is extremely hot (in the neighborhood of 6,000 degrees Centigrade) and so has a relatively high ion density, and good electrical conductivity. The current is carried through this region largely by the electrons, since they move much more readily than the positive ions because of their small mass. However, equal numbers of positive ions and negative electrons are interspersed throughout the arc stream, so no net space charge exists, and the only resistance to the motion of the electrons is that supplied by frequent collisions with inert atoms and molecules.

Near the anode surface, the conditions are not as favorable for the conduction of current. The electrode tip is about 2,000 degrees cooler than the arc stream, and the gas immediately adjacent consists largely of carbon vapor in temperature equilibrium with the surface. At 3,700 degrees Centigrade, this carbon vapor is a very poor conductor of electricity. It therefore requires a high voltage to force the current-carrying electrons through this vapor layer and into the anode. In a pure carbon arc, this anode drop is about 35 volts. Most of the heat so developed is transferred to the surface of the positive carbon, part by the impact of the highly accelerated electrons and part by thermal conduction. Finally, as the electrons reach the anode surface, they release their heat of condensation, contributing further to the high temperature of the electrode tip.

The positive electrode of the low-intensity arc may contain a core consisting of a mixture of soft carbon and a potassium salt. The potassium does not contribute to the light, but does increase the steadiness of the arc by lowering the effective ionization potential of the arc gas.

Flame arcs. A flame arc is obtained by enlarging the core in the electrodes of a low-intensity arc and replacing part of the carbon with chemical compounds known as flame materials, capable of radiating efficiently in a highly heated gaseous form. These compounds are vaporized along with the carbon and diffuse throughout the arc stream, producing a flame of a

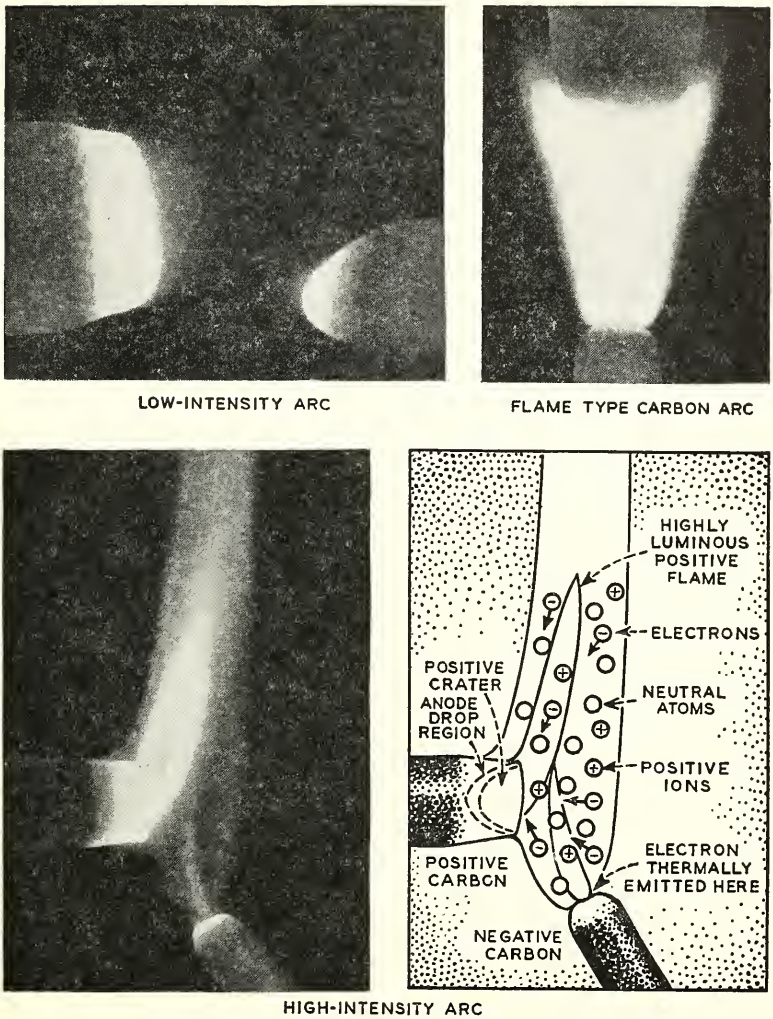


FIG. 1-10. Low-intensity arc, 30 amperes, 55 volts, direct current. Flame arc, 60 amperes, 50 volts, alternating current. (Direct current flame arcs very similar.) High-intensity arc, 125 amperes, 70 volts, direct current (rotating positive carbon).

color determined by the compounds used. Typical flame materials are iron for the ultraviolet, rare earths of the cerium group for white light, calcium compounds for yellow, and strontium compounds for red. (See Fig. 1-10.)

Such flame materials have a considerably lower ionization potential than carbon. This greater ease of ionization reduces the temperature of the

anode layer necessary for the conduction of current into the anode and results in a lower anode voltage drop (about 15 volts). The lower anode power input reduces the area and brilliance of the anode spot so that its contribution to the total light becomes unimportant. The radiation emitted by the flame arc consists chiefly of the characteristic line spectra of the elements in the flame material and the band spectra of the compounds formed. The excitation of the line and band spectra is thermal in nature, caused by the high temperature of the arc stream gas. The concentration of flame materials in the arc stream is not very high, so that the flame arc, while brighter than many other light sources, is considerably less bright than either the low or the high intensity arc. Since the whole arc flame is made luminous, however, the light source is one of large area, and high radiating efficiencies (up to 80 lumens per watt) are obtained.

High-intensity arcs. The high-intensity arc is obtained from the flame arc by increasing the size and the flame material content of the core of the anode, and at the same time greatly increasing the current density, to a point where the anode spot spreads over the entire tip of the carbon. This results in a rapid evaporation of flame material and carbon from the core so that a crater is formed. The principal source of light is the crater surface and the gaseous region immediately in front of it. (See Fig. 1-10.) Since the flame material is more easily ionized than the carbon, a lower anode drop exists at the core area than at the shell of the carbon. This tends to concentrate the current at the core surface, and so encourages the formation of the crater.

The increased brightness of the high-intensity arc is produced by radiation resulting from the combination of the heavy concentration of flame materials and the high current density within the confines of the crater. Although the primary radiation of this gas is the line spectrum of the constituent atoms, and the peak intensity of any one line is limited to that of a blackbody at the temperature of the crater gas, the energy exchange is so intense that the lines are broadened by absorption and re-radiation into a partially continuous spectrum. The sum of this continuous and line radiation can be so great as to give a brightness over ten times that of the low-intensity arc.

Gaseous Discharges

The fundamental processes involved in the production of light are the same for all types of vapor lamps. The activity in a low-pressure mercury discharge tube such as the commercial fluorescent lamp is exemplary of all types.

Ultraviolet radiation from mercury (with the lowest boiling point of all metallic elements) used in fluorescent lamps, like the sodium yellow, neon red-orange, or cadmium red radiation is the result of changes in atomic energy caused by the transition of an electron from one energy state or orbit to another.

Physical activity in a mercury-discharge tube. In Fig. 1-11, a minute cross section of a fluorescent lamp has been magnified to show the sequence of steps which result in emission of ultraviolet radiation.

1. A high-speed *free* or *conduction* electron boiled off one of the electrodes collides with a valence electron of the mercury atom and excites it by knocking it from its normal energy level to a higher one.

2. The conduction electron loses speed at the impact and changes direction, but may continue along the tube to excite one or more additional atoms before completing its path through the lamp.

3. The valence electron returns presently to its normal energy level and liberates by its transition (in this particular instance) a quantum of ultraviolet radiation.

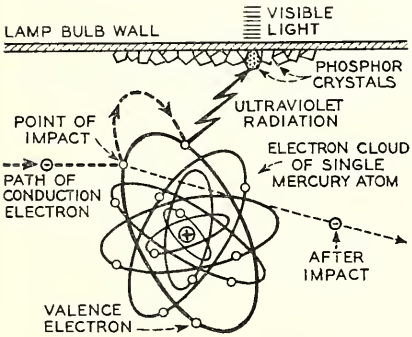


FIG. 1-11. Magnified cross section of fluorescent lamp showing progressive steps in luminescent process which finally result in the release of visible light.

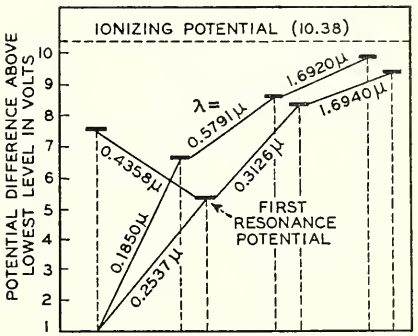


FIG. 1-12. Simplified energy diagram for mercury showing a few of the characteristic spectral lines.

The *wavelengths of radiation emitted* depend on the energy transferred in the collisions. Radiation may be emitted in any one of several wavelengths (in the ultraviolet, visible, or infrared regions) which are characteristic of transitions between two mercury energy levels. The wavelength varies inversely with the voltage difference in accordance with the relationship:

$$\text{wavelength } \lambda = \frac{1.2336}{V_d} \text{ microns}$$

where V_d is the potential difference (volts) between two energy levels through which the displaced electron has fallen in one transition.

This relationship, which applies to luminescence regardless of the elements involved, shows that when visible wavelengths are emitted the potential difference must be between 3.2 volts for violet (0.380 micron) and 1.6 volts for red (0.760 micron) light.

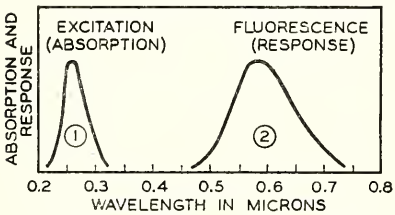
Figure 1-12 is a greatly simplified version of the mercury energy level diagram showing a few of the possible wavelengths in which energy may be radiated from a mercury atom.

Complete energy diagrams permit speculation as to the relative desirability, from the standpoint of luminous efficiency, of using different materials in vapor lamps. However, in such a speculation the energy concentrated in each wavelength is equal in importance to the wavelengths themselves, and is proportional to the number of transitions occurring per second between the voltage difference related to each wavelength. It is a function of the number of conduction electrons and valence electrons available in the normal state and is difficult to compute.

Fluorescence and Phosphorescence

The *fluorescent lamp* is a relatively simple modification of the ordinary mercury lamp. By varying the coating on the inside of the tube a wider variety of colors may be obtained conveniently than by merely adjusting voltage, pressure, or the gas mixture.

Upon release from the excited mercury atom (Fig. 1-11), the ultraviolet quantum ($\lambda = 0.2537$ micron) may strike one of the phosphor crystals on the surface of the tube. The phosphor will transmit this energy unaffected until the quantum reaches an "active center," where it starts a process similar to that by which the mercury atom was excited (by the impact of the electron) and releases a photon of visible radiation. (See Fig. 1-13.)



1 micron = 10,000 angstroms = 1/10,000 centimeters

FIG. 1-13. Fluorescence curve of zinc-beryllium-silicate phosphor showing initial excitation by ultraviolet rays and subsequent release of visible radiation.

Phosphors that may be excited to release visible radiation are coated on the inside of the fluorescent lamp in the form of a microcrystalline powder of exceptionally high chemical purity.

Less than 0.01 per cent of certain impurities in a phosphor may reduce the lumen per watt rating of the lamp in which it is used by 20 per cent. Very small percentages of other "intentional impurities" called *activators* are usually required for efficiency.

Figure 1-14, a simplified energy diagram for zinc sulphide, provides an explanation. To release radiation from a crystal of pure zinc sulphide, an electron resting at energy level A must be knocked up to excitation level D. Since it requires a great deal of energy to effect such a large transition, the process is inefficient at best and may never occur.

Addition of a very small quantity of an activator (copper) results in the presence of electrons of the copper atoms at intermediate energy levels B and C. By comparison with those at level A, the activator electrons are relatively free to move about and since they are initially at a higher level, less energy is required to knock them up to level D.

The return of electrons from excitation level D to intermediate level C or B or A in small steps will result in the release of visible radiation.

If the luminescent process continues only during the excitation it is called *fluorescence.*

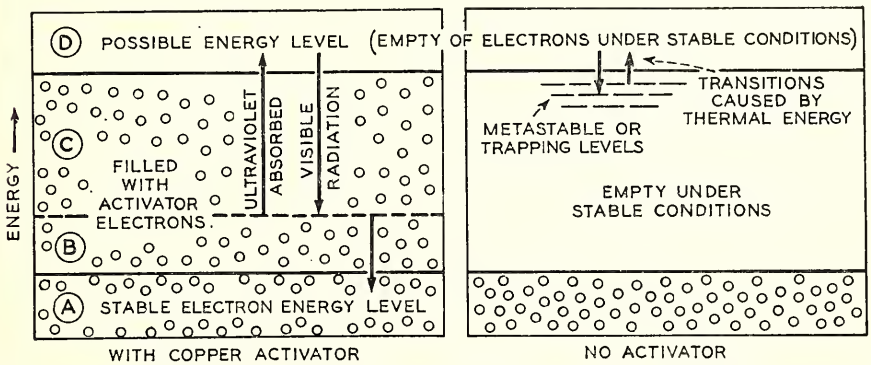


FIG. 1-14. Simplified energy diagram for copper-activated zinc sulphide phosphor.

Some materials continue to emit light after the source of excitation energy has been removed. This phenomenon is called *phosphorescence.* It results from the transition of an electron from one of the *metastable* or trapping levels (Fig. 1-14) to which it may have been knocked during excitation from B or C, or in which it may have been stopped on its return from D. The release is effected by the thermal energy of the crystal.

Effect of temperature. If the temperature of the crystal is maintained at a low value the electrons may be trapped for an indefinite period of time, finally being released when the crystal is heated, minutes or even hours after excitation.

Relationship between activation impurity and efficiency. Table 1-5 and Fig. 1-15 show the critical relationship which may exist between activator, impurity, and efficiency in fluorescent lamps.

Table 1-5. Effect on Fluorescent Lamp Efficiency of Small Quantities of Impurities in the Phosphor[4]

TEST LAMP*	PER CENT IRON	EFFICIENCY† (lumens per watt)
1	0.001	62.0
2	0.01	56.2
3	0.10	48.7
4	1.0	9.0

* Coated with zinc silicate $ZnO \cdot SiO_2$ + 1 per cent manganese contaminated with the indicated quantities of iron impurities.

† Neglecting ballast consumption.

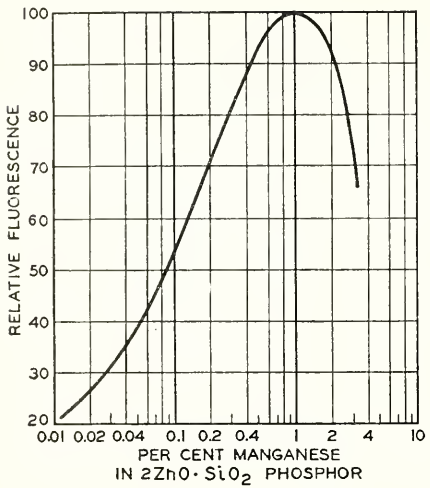


FIG. 1-15. Effect of activator concentration on fluorescence of zinc silicate.

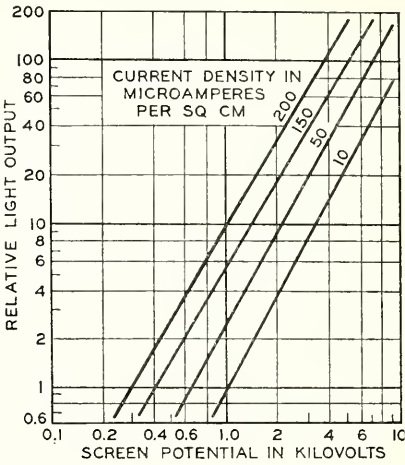


FIG. 1-16. The light output of zinc sulphide is a function of screen potential and current density in a cathode-ray tube.

Table 1-6 reveals the color effect of activator changes. Table 1-7 includes the characteristic color of radiation emitted by several common phosphors.

Stokes law, which states that the emitted radiation must be of longer wavelength than that absorbed, is based on two facts:

1. Relatively large quanta (associated with short wavelengths) are required to raise electrons to the high excitation energy levels from which fluorescent and phosphorescent processes may begin.

2. Transition of displaced electrons to their stable level usually occurs in several short steps giving rise to the smaller quanta associated with longer wavelengths.

Note: Certain "anti-stokes" emitters exist which store energy in the metastable or trapping levels and will release wavelengths shorter than those required to excite them.[5]

Table 1-6. Effect of Activators on the Wavelength of Light Emitted by a Phosphor

PHOSPHOR (*per cent by weight*)		WAVELENGTH OF MAXIMUM FLUORESCENCE (micron)	
Zinc sulphide	*Cadmium sulphide*	*Activator* *Silver*	*Copper*
100	0	0.4600	0.5230
90	10	.4740	.5400
80	20	.4920	.5790
75	25	.5030	.6100

Table 1-7. Color Characteristics of Several Inorganic Phosphors

MATERIAL	ACTIVATOR	PEAK OF FLUORESCENT BAND (micron)	COLOR OF FLUORESCENCE
Zinc silicate	Manganese	0.5260	Green
Zinc beryllium silicate	Manganese	.5925	Yellow-white
Cadmium borate	Manganese	.6150	Pink
Cadmium silicate	Manganese	.5950	Yellow-Pink
Magnesium tungstate	None	.4820	Bluish-white
Calcium tungstate	None	.4130	Blue
Calcium tungstate	Lead	.4420	Blue
Calcium phosphate	Cerium	.3600	*
Calcium phosphate	Thallium	.3325	*
Calcium phosphate	Cerium and manganese	.6500	Red

* Ultraviolet radiation.

Miscellaneous Forms of Luminescence

The electron excitation which results in the following luminescent processes is fundamentally the same as that which takes place in a fluorescent lamp.

Cathodoluminescence is the phenomenon observed when the screen of a cathode-ray tube such as that used in a television or radar receiver is bombarded with high-voltage electrons.

Figure 1-16 indicates the variation of light output for various conditions of voltage and current density.

In an experimental television projection tube operating at 30,000 volts, a brightness of about 10,000 candles per square centimeter has been produced with a beam intensity of 20 watts on a spot 0.5 square millimeter in area. It was accompanied by rapid deterioration of the phosphor.

Certain chemical reactions proceeding at room temperature are accompanied by the production of light. This is known as *chemiluminescence*. The oxidation of phosphorus in air and of pyrogallol in solution are familiar examples.

A type known as *bioluminescence* occurs when luciferin, a substance synthesized by living cells, is oxidized in the presence of molecular oxygen and an enzyme, luciferase.

The phosphorescence of sea water results from the presence of an enormous number of unicellular organisms which secrete luciferin and luciferase and oxidize when the disturbance of the water excites them.

The firefly exhibits a similar ability.

Triboluminescence is the term applied to light produced by friction or crushing. The phenomenon may be observed when pressure-adhesive tapes are unrolled or when lumps of cane sugar are rubbed together in a dark room.

Natural Phenomena

Sunlight. Energy of color temperature about 6,500 Kelvin is received from the sun at the outside of the earth's atmosphere at an average rate of about 0.135 watt per square centimeter. About 75 per cent of this energy is transmitted to the earth's surface at sea level (equator) on a clear day.

The apparent brightness of the sun is approximately 160,000 candles per square centimeter viewed from sea level. Illumination of the earth's surface by the sun may be as high as 10,000 footcandles; on cloudy days the illumination drops to less than 1,000 footcandles. See Section 9.

Sky light. A considerable amount of light is scattered in all directions by the earth's atmosphere. The investigations of Rayleigh first showed that this was a true scattering effect. On theoretical grounds the scattering should vary inversely as the fourth power of the wavelength when the size of the scattering particles is small compared to the wavelength of light,[6] as in the case of the air molecules themselves. The blue color of a clear sky and the reddish appearance of the rising or setting sun are common examples of this scattering effect. If the scattering particles are of appreciable size (the water droplets in a cloud, for example), scattering is essentially the same for all wavelengths. (Clouds appear white.)

Polarization in parts of the sky may be 50 per cent complete.

Moonlight. The moon shines purely by virtue of its ability to reflect sunlight. Since the reflectance of its surface is rather low, its brightness is approximately 1,170 footlamberts.

Lightning. Lightning is a meteorological phenomenon arising from the accumulation in the formation of clouds, of tremendous electrical charges, usually positive, which are suddenly released in a spark type of discharge.

The lightning spectrum corresponds closely with that of an ordinary spark in air, consisting principally of nitrogen bands, though hydrogen lines may sometimes appear owing to dissociation of water vapor.

Aurora borealis (northern lights). These hazy horizontal patches or bands of greenish light on which white, pink, or red streamers sometimes are superposed appear between 60 and 120 miles above the earth. Apparently, they are caused by electron streams spiraling into the atmosphere, primarily at polar latitudes. Some of their spectrum lines have been identified with transitions from metastable states of oxygen and nitrogen atoms.

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SECTION 2

LIGHT AND VISION

Joint professional responsibility. Though the ophthalmologists and optometrists are responsible for the care of the eyes, their ultimate success in the discharge of this responsibility depends in part on the co-ordinated skills of the architect, decorator, and illuminating engineer.

Effect of poor illumination. If forced to live or work under conditions of insufficient or poor quality illumination, or both, persons with normal eyes frequently experience temporary discomfort or disability that reduces their visual efficiency. Over a period of time they have been known to suffer semipermanent or permanent impairment of vision.[1]

Benefits of good illumination are greatest for those with subnormal vision. Lacking light, the best eyes are useless. The vision of those persons whose visual deficiency the specialist is unable to correct or has not corrected to normal (through the prescription of proper training, or of lenses, medication, or surgery) is more noticeably affected by the quantity and the quality of illumination than is the vision of persons with normal or corrected to normal vision.

For these reasons the illuminating engineer shares with the eye specialist the responsibility for providing the public with the means for achieving and maintaining the best vision attainable within the limits of engineering development and economic feasibility. Demonstrations of co-operation between practitioners in each field are becoming more common as it is realized that the objectives of the professions are the same.

Industrial progress in sight conservation. The trend in industry is toward the assignment of vision problems, including those related to job analysis, to committees or boards comprising a medical director, a safety engineer, an ophthalmologist or optometrist, and an illuminating engineer.[2]

The American Standard Safety Code for the Protection of Heads, Eyes, and Respiratory Organs, published by the National Bureau of Standards, describes the most common occupational eye hazards and means of preventing eye injuries, and includes specifications for goggles designed to protect against glare, invisible radiation, fumes, and flying particles.

Child development research. In Texas, where a long-range research into child development is being conducted, illuminating engineers and eye specialists are prominent in the interprofessional commission organized to guide the program.[3]

The Visual Process

The *functions of the eye* all depend on its ability to transform a light stimulus into an impulse that may be transmitted through the nerve fibers to the brain. There, the impulse is analyzed and a reaction initiated. The undistorted perception of contrast and color, of shape and depth, and of motion and direction, and therefore, most voluntary thought and action depend on the consistent response of the eye to light.

NOTE: References are listed at the end of each section.

Seeing skills must be learned and therefore are not uniformly developed in all individuals. Visual training in many instances is an un-co-ordinated and forgotten phase of instruction in some other skill, and may exist only in an unconscious trial and error process initiated during the development of a related dexterity (of the fingers, for example). There are notable examples, however, of co-ordinated visual training.

Several successful programs were conducted on a very large scale during World War II by the armed services. These prepared personnel for assignments (as lookouts, photo interpreters, and so on) requiring the highest possible development of certain visual skills.

In industry, special visual equipment, instruction, and practice is required in many operations, particularly in those involving inspection.

Educators have found that slow readers may sometimes improve both speed and accuracy if given proper visual instruction.

Psychological considerations introduced during the learning period may account, at least in part, for individual color preferences and the association of certain colors with temperature levels.

The Structure of the Eye

The structure of the eye is often compared with that of a camera, as in Fig. 2-1*A*.

The *iris* is an opaque fibrous membrane resting against the crystalline lens. Reflexes in this membrane result in variations of the diameter (0.079 to 0.315 inch) of its central aperture, the pupil.

The attendant variations in area of the pupil (0.00465 to 0.0775 square inch) provide compensation by factors between 1 and 16 for wide variations in the brightness of the field of view. The pupil is similar in its function to the aperture stops in a camera. Compensation for the extremely wide range of brightness encountered in nature also involves the adaptation process.

The *ciliary muscles* comprise the focusing mechanism of the eye. By controlling the curvature of the crystalline lens, they change the focal length of the cornea-lens optical system to permit near vision.

In the relaxed state, the lens (with an equivalent focal length of 0.59 inch) forms on the fovea a sharp inverted image of objects at distances between 20 feet and infinity located along or close to its optical axis. An image about 0.036 inch high is formed of a man 100 feet away.

To focus on near objects (closer than 20 feet) the muscles must be tensed.

The *retina* comprises millions of light-sensitive nerve endings distributed throughout an almost transparent membrane about 0.0087 inch thick. An enlarged and simplified cross section of these nerve endings is shown in Fig. 2-1*B*.

The *light-sensitive nerve endings* of the retina have their counterpart in tiny particles of photosensitive chemicals that give a photographic emulsion its image preserving ability. The size and the distribution of these

nerve endings limit the resolving power or visual acuity of the eye in somewhat the same manner that particle size and dispersion control the "graininess" of a photographic emulsion. They are attached individually or in groups to fibers of the optic nerve.

There are two distinct types of nerve endings, known because of their shape as *rods* and *cones*.

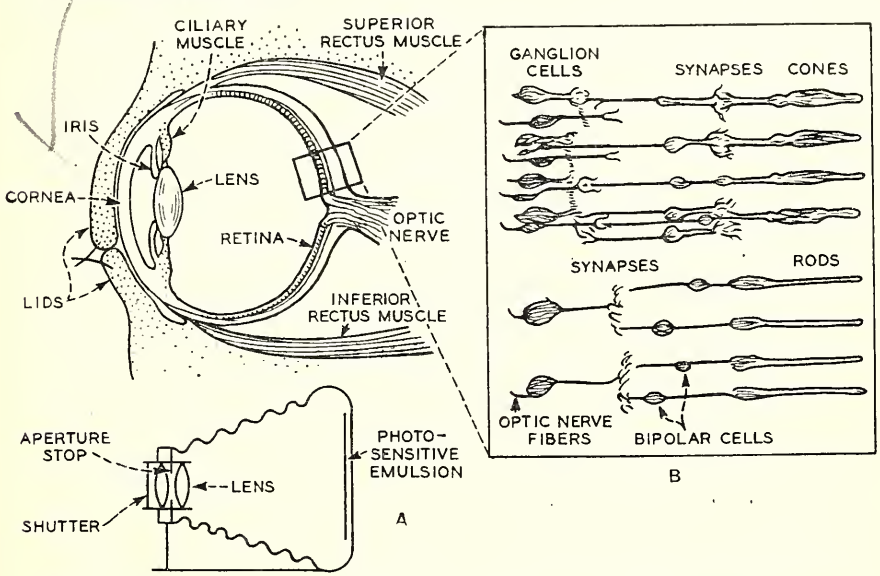


FIG. 2-1*A*. Simplified vertical cross section of the human eye showing its camera-like structure. *B*. Magnified section of the retina simplified to show only the principal nerve structures.

Cones approximately 0.000126 inch in diameter found throughout the retina are concentrated in the fovea, an oval-shaped mosaic (approximately 0.0118 inch by 0.00945 inch along its axes). The cones of the fovea are connected individually to single fibers of the optic nerve. Best available data suggest that the entire retina includes 6.3 to 6.8 $\times$ 10^6 cones.[4]

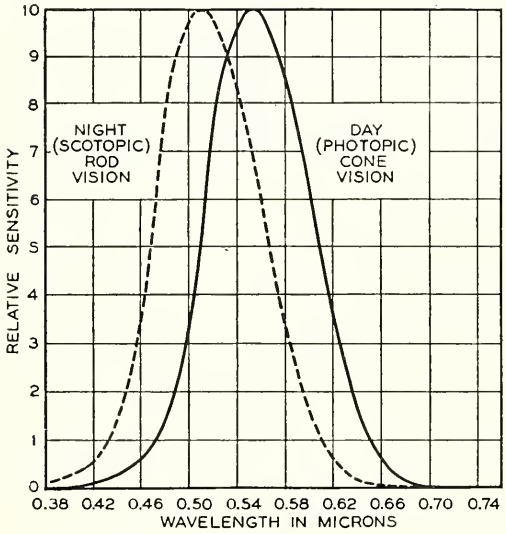
The section of the retina containing cones only includes the fovea and the area immediately surrounding the fovea; this section subtends a 1- to 2-degree angle which has its apex in the iris plane.

Photopic (*cone*) *vision* exclusively is used for the discrimination of fine detail in critical seeing tasks and for the discrimination of color. The relative sensitivity curve of cones is given in Fig. 2-2. Because of their small diameter, close packing, and individual connections to the optic nerve, cones transmit a very sharp image showing considerable detail. Having low sensitivity they contribute little to the visual sensation when brightnesses in the field fall below 0.01 footlambert, as at night.

Rods approximately 0.00197 inch in diameter are dispersed throughout the parafoveal retina in a lower concentration per unit area than of cones in the fovea. The concentration of rods continues to decrease as their

distance from the fovea is increased, and they are usually connected in groups to a single fiber of the optic nerve. Between 110×10^6 and 125×10^6 rods have been counted in the retina.[4]

Scotopic (rod) vision begins to function when field brightnesses drop below 0.01 footlambert. The gray appearance (regardless of color) of objects under low illumination levels is one consequence. Because of the coarse rod reception mosaic and the multiple connections of rods to single nerve fibers, sharp images are not transmitted and objects appear as fuzzy silhouettes. The optical axis for rod vision is removed by 5 to 10 degrees from the fovea. As a result one usually sees best by somewhat averted vision at low brightness levels.



1 micron = 10,000 angstroms = 1/10,000 centimeter

FIG. 2-2. Relative spectral sensitivity curves for photopic (cone) and scotopic (rod) vision showing the Purkinje effect on the wavelength of maximum sensitivity.

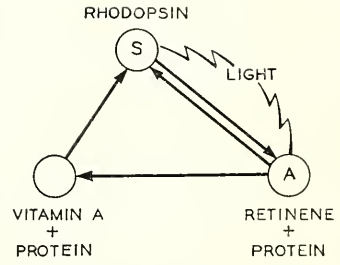


FIG. 2-3. In the rods, both chemical and photochemical activity has been observed involving rhodopsin, retinene, vitamin A, and protein.

The *macular pigment*, a yellow layer covering the fovea and area immediately surrounding it, is believed to be one cause of the difficulty of obtaining identical color matches from different observers. Since it varies in color between individuals and appears to deepen in color with age, the spectral composition of light that must pass through it before the cones are stimulated will be modified and thus modify any judgement passed by an observer making a color match.

The Photochemical Theory

Because of the complexity of the visual process, which includes many uncontrollable variables, a complete investigation of most visual phenomena is almost impossible at the present time. Nevertheless, sufficient experimental evidence has been collected to justify the general acceptance of the fundamental concepts of the photochemical theory of vision.[5]

The theory proposes that each neurone (rod or cone) contains a photosensitive substance S that forms upon exposure to light (among other things) a substance A. Also, there is a chemical reaction by which S is produced. Though the exact composition of the chemicals involved is not known, researches[6] support the belief that in the rods S is rhodopsin or visual purple, a rose-colored liquid; A is retinene, a yellow decomposition product; and vitamin A is an intermediate product in the chemical reaction. It appears that the relationship between these substances is as shown in Fig. 2-3. The speed of *photochemical* reactions between S and A is rapid as compared with that of the *chemical* process that includes production of vitamin A.

Though it is believed similar reactions take place in the cones, the chemicals of the human cones have not been isolated.

In an attempt to fit the theory to the available experimental data on dark adaptation, a modification has been proposed.[7] It includes five postulates: three expressions for the velocity of the reactions just described and two expressions for the frequency of electrical impulses by which visual stimuli are transmitted through the optic nerve to the brain.[8] The modification has the advantage of generality over earlier forms of the theory that makes possible its application to the mathematical analysis of any visual phenomenon. Good correlation has been obtained with several experimental data but unexplained deviations from others have been noted.

Color discrimination, though known to depend on the proper functioning of the cones, is not yet understood.

It has been proposed that three types of photosensitive chemicals exist in the cones and that each has a distinct spectral absorption curve.[9] The existence of three types of nerve fibers, through which primary color stimuli may be transmitted as distinct impulses, has also been suggested.[10]

Though all colors appear gray at low illumination levels because of the deficiency of the rods, which provide no color perception, the relative brightnesses of different colored surfaces having the same reflectance or of sources emitting equal quantities of energy of different wavelengths will depend on the colors involved. In general, yellow-greens will appear brighter than reds or blues. Similar in shape to the curve for the cones, the peak of the rod sensitivity curve is displaced toward the shorter wavelengths. (See Fig. 2-2.) This displacement, known as the *Purkinje effect*, occurs gradually as the observer adapts to low brightnesses and depends more upon the rods and less upon the cones.

The *adaptation of the eye* to different brightness levels *above 0.01 footlambert* involves only the cones and is complete after 10 minutes of exposure to each new field. For most practical purposes the process may be considered complete after 0.5 to 2 minutes of exposure.

Dark adaptation is the term used to describe adaptation to levels *below 0.01 footlambert*. In the transition region between 0.01 and 0.001 footlambert this will involve both rods and cones. Only rods are operative at levels below 0.001 footlambert.

The rate of adaptation is a function of the initial adaptation level and of the color to which the eye has been exposed. Initial exposure to high brightness levels of blue (short wavelength) radiation causes reduced rates of adaptation (greater total time). Though it has been found that the adaptation level may continue to decrease for several hours if the eyes are kept in darkness, for practical purposes the process may be considered complete after 30 minutes.

Factors of Vision

For evidence of the similarity of the objectives of the eye specialist and the illuminating engineer, it is only necessary to compare the criteria, i.e., the factors of vision, against which each group judges adequacy of illumination:

ILLUMINATING ENGINEER	EYE SPECIALIST
Visual acuity	Visual acuity
Contrast	Visual efficiency
Time or speed	Visual speed
Brightness	Visual comfort
	Visual health

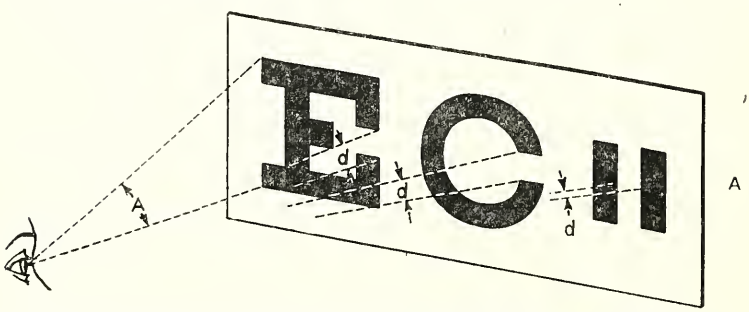


FIG. 2-4*A*. Common visual acuity test objects showing detail (d) to be seen and the maximum angle subtended (A). For normal vision $d_{min} = 1$ minute. In most test objects $A = 5d$.

Visual Acuity

Visual acuity is the ability to distinguish fine detail. Eye specialists express it either as a *ratio* of the distance at which a given line of letters on a Snellen test chart can be seen by the observer being tested to the distance at which an observer with normal vision could see it, or as a *visual efficiency rating* (expressed in percentages) related to the size of character in each line, if the American Medical Association chart is used.

Most persons with apparently normal vision can distinguish the details of a black object on a white background if the detail subtends at least 1 minute at the eye.

At an observation distance of 20 feet (arbitrarily selected as representative of distance vision) the characters in the *normal* lines of both charts (20/20 Snellen, 100 per cent A.M.A.) subtend 5 minutes and their detail subtends 1 minute. Details in the 20/10 line subtend 1 minute at 10 feet and those in the 20/40 line subtend 1 minute at 40 feet. Thus a person with Snellen rating of 20/40 sees at 20 feet what a normal observer would see at 40 feet.

LINE	RATING	A.M.A. TEST CHART	SNELLEN TEST CHART	RATING	LINE
			L E F O D P C T	20/15	9
1	100%	L T V U P R N Z C F D N C	D E F P O T E C	20/20	8
2	95%	F D N E C H B S C Y R L	F E L O P Z D	20/25	7
3	90%	T Y O D Z E C H B P	E D F C Z P	20/30	6
4	85%	U P N E S R D H	P E C F D	20/40	5
5	80%	C V O F E H S			
6	75%	O C L C T R	L P E D	20/50	4
7	70%	N R T S Y F			
8	65%	E O B C D	T O Z	20/70	3
9	60%	U F V P			
10	55%	H T S C			
11	50%	P E R	F P	20/100	2
12	45%	D B C			
13	40%	Y L V			
14	35%	F P			
15	30%	N Z			
16	25%	O C			
17	20%	H E	E	20/200	1

B

FIG. 2-4*B*. Comparison of reduced size Snellen and A.M.A. visual acuity test charts. (The standard A.M.A. chart is printed on two sides of a single card.)

Visual acuity is also expressed (by the research worker) as the reciprocal of the angle (minutes) which the smallest detail in a test object subtends at the eye.

A laboratory acuity value of *one* means that the observer can just perceive a test object which subtends 1 minute at the eye; a value of two denotes that an 0.5 minute object can just be distinguished.

Figure 2-4 shows three common test objects and the relationship between Snellen and A.M.A. lines and ratings. A uniform illumination of 10 foot-candles on the charts should be provided for routine examinations.

Visual acuity increases with the brightness of the task. The results of one study of the relationship are plotted in Fig. 2-5*A*, which indicates that the rate of increase in visual acuity with increased brightness diminishes at high values of background brightness. The curve rapidly approaches a maximum at brightnesses greater than 10,000 footlamberts.[11]

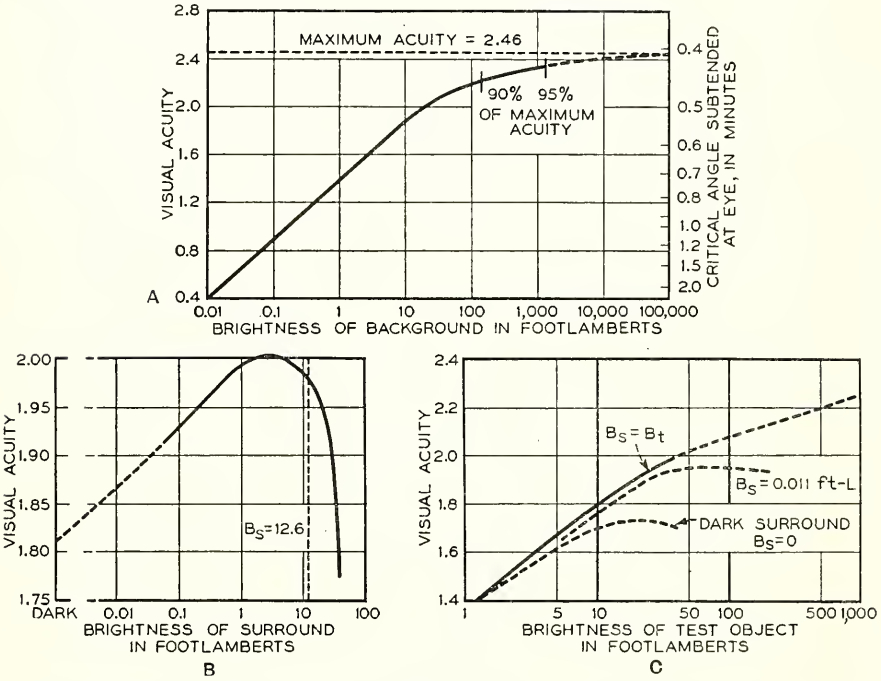


FIG. 2-5. Maximum acuity for any test object is attained when the surround brightness does not exceed that of the task, and is not less than one tenth that of the task.

A. Variation of acuity with background brightness for a black test object on a white background. *B*. Variation of acuity with surround brightness for constant brightness test object (B_t = 12.6 footlamberts). *C*. Acuity versus test object brightness for three values of surround brightness.

The *maximum achievable visual acuity* is believed to be approximately 2.46 (visual angle = 0.406 minute with the international test object).[12] Ninety and 95 per cent maximum acuity may be attained at 150 footlamberts and 1,300 footlamberts, respectively. To attain more than 95 per cent maximum acuity, the brightness required is more than 1,300 footlamberts (as in nature). Maximum acuity may be obtained only when the surrounding brightness does not exceed that of the task and is not less than one tenth that of the task. (See Fig. 2-5*B* and Table 2-1, pg. 2-12.)

Contrast

If an object is to stand out against a background, there must be contrast between the two. *Contrast is the difference in brightness between the object and its background divided by the brightness of the background*:

$$C = \frac{B_1 - B_2}{B_1}$$

where C = contrast
B_1 = brightness of background (footlamberts)
B_2 = brightness of object (footlamberts)

since brightness, B, equals illumination, E, $\times$ reflectance ρ

$$C = \frac{E\rho_1 - E\rho_2}{E\rho_1} = \frac{\rho_1 - \rho_2}{\rho_1}$$

where E = illumination (footcandles)
ρ = reflectance (perfectly diffuse surface only)

The effects of contrast may be divided into two classes:
(1) contrasts of small objects against their background, and
(2) contrasts between large contiguous surfaces.
The first involves the variation of contrast with size, as well as with illumination. In the second, size is not a factor.

Small objects vs. background. The relationships between acuity, contrast, and brightness for the range of brightness between 0.0001 and 100 footlamberts are shown in Figs. 2-6*A* and 2-6*B*.

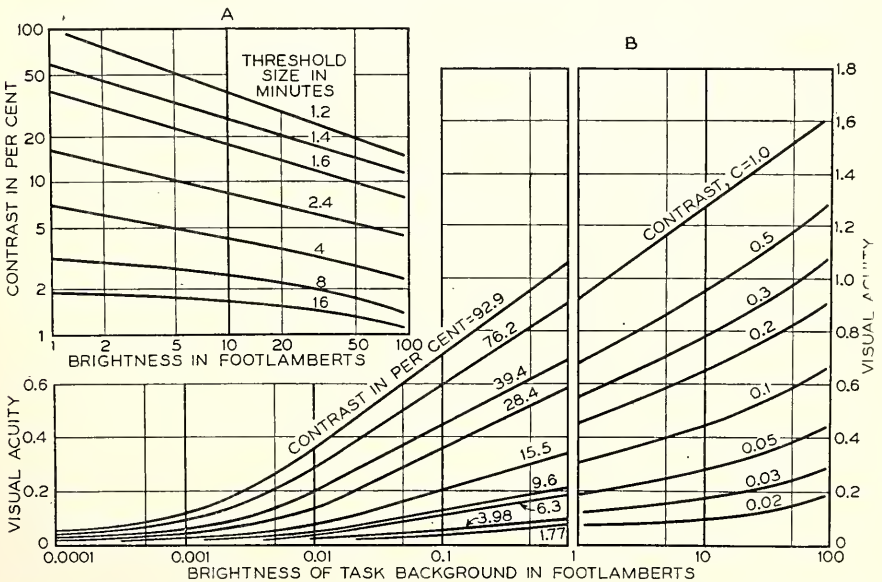


FIG. 2-6. Relationships between contrast, brightness, and acuity. *A*. Relationship between contrast and brightness for threshold visibility (constant exposure time). *B*. Acuity attainable for various values of brightness with objects of different contrasts.[13, 14]

Large contiguous surfaces. The minimum perceptible contrast between a background and a large contiguous surface:

$$C_{\min} = \frac{(B_1 - B_2)_{\min}}{B_1},$$

is not easy to determine accurately by experiment since the fovea becomes adapted very rapidly to changing brightness. If the time of exposure is not carefully regulated, the result is not the minimum perceptible contrast but a value related to an adaptive brightness between the brightness of the background and that of the test area. Figure 2-7 shows minimum perceptible contrast and contrast sensitivity for various values of background brightness.

Contrast sensitivity ($1/C_{min}$) is similar in concept to visual acuity. It is a measure of the ability to discriminate slight contrasts. *Ninety-five per cent* of maximum contrast sensitivity may be obtained with a brightness of 90 footlamberts. *Ninety per cent* is obtained with 20 footlamberts.

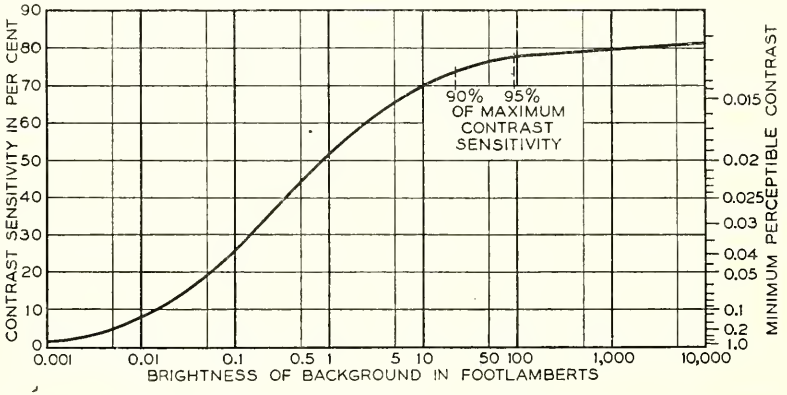


FIG. 2-7. Minimum perceptible contrast and contrast sensitivity versus background brightness.

Speed of Vision

It takes time to see. Speed of vision is a function of task brightness as shown by Fig. 2-8*A*. Considering the difference of test objects and observers, these data agree very well with results of later work on international test objects, as plotted in Fig. 2-8*C*.

In reading a steel vernier rule, the speed of making the complete reading (tenth inch numbers, quarter divisions within the tenth, and exact position of the 25 part vernier) varies, as shown in Fig. 2-9*A*, with the brightness of the highlight on the background of the rule against which the black divisions appear in bold relief.[16]

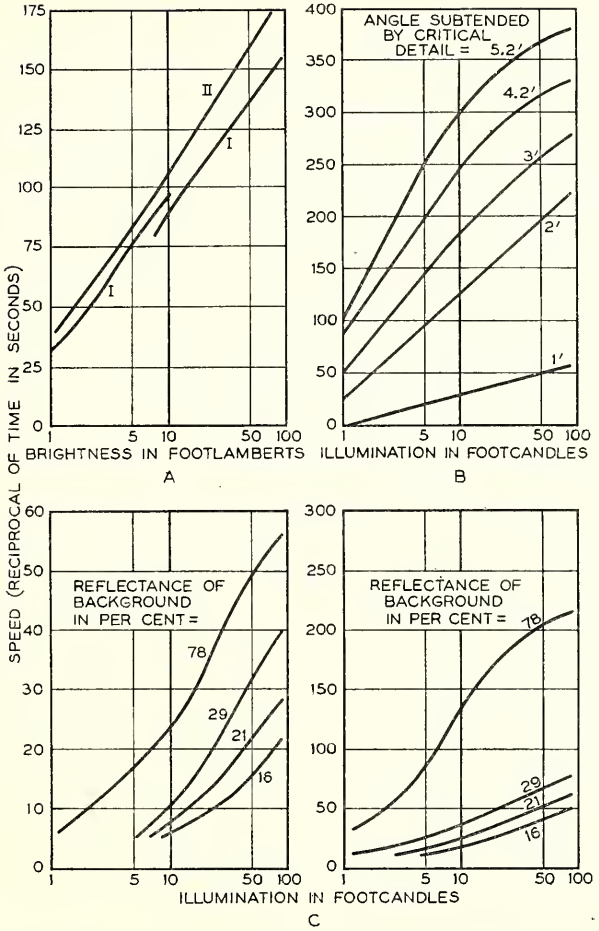


FIG. 2-8. Speed of vision vs. size, contrast, and illumination of the task. *A*. (*I*) Speed of noting the presence of 2.43 minute black dot. (*II*) Speed of noting the orientation of 1.82 minute parallel bar test object.[14, 15] *B*. Speed of noting orientation of various sizes of black (ρ = 3 per cent) on white (ρ = 78 per cent) parallel bar test object. *C*. Speed of reporting orientation of black (ρ = 4 per cent) international test objects (right, 1 minute and left, 2 minutes) viewed against various backgrounds.[15]

Figures 2-9*B* and 2-9*C* show speed of vision variations for other tasks.[16, 17]

Brightness

Because it is the brightness of a surface rather than the illumination (footcandles) it intercepts which is utilized in seeing, misapplications may occur when footcandle levels recommended by the illuminating engineer for high reflectance surfaces are applied to dark surfaces.

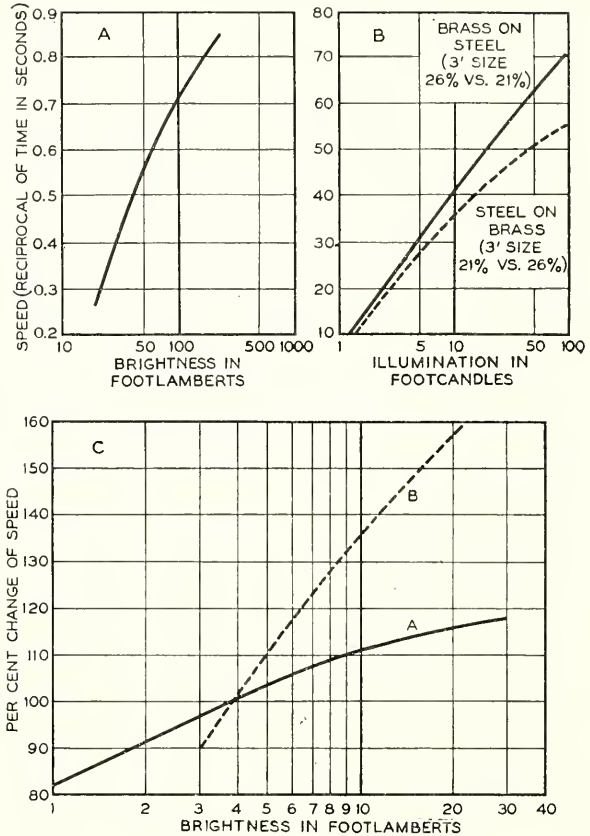


FIG. 2-9*A*. Speed of reading steel vernier rule vs. brightness of highlight surrounding black divisions.[16] (Reading requires perception of 1/1000 inch deviation from alignment of divisions.) *B*. Speed of discriminating brass and steel test objects against contrasting backgrounds.[16] *C*. Speed of reading vs. illumination (black Old English type on: *A*, white (ρ = 80 per cent) background; *B*, gray (ρ = 23 per cent) background.[17]

Table 2-1. Relationship between Brightness Visual Acuity and Contrast Sensitivity

BRIGHTNESS REQUIRED		MAXIMUM POSSIBLE ATTAINMENT UNDER IDEAL CONDITIONS (per cent)
Visual Acuity*	Contrast Sensitivity	
1,300 footlamberts	90 footlamberts	95
150 footlamberts	20 footlamberts	90

* Black test object on white background.

The brightness in footlamberts of any nonspecular surface equals the incident illumination (footcandles) times the reflectance. Under the same illumination, the brightness of white paper (reflectance 80 per cent) will be four times that of cast iron (reflectance 20 per cent).

Visual acuity, contrast sensitivity, and time vary directly and largely logarithmically with brightness. Table 2-1 represents the best information presently available on the relationship between brightness, visual acuity, and contrast sensitivity. The effect of time is shown in Figs. 2-8 and 2-9.

British Interior-Lighting Code

The British (I. E. S.) code of interior lighting includes recommended illumination levels. These levels are estimated, on the basis of laboratory tests and standard test objects, to be sufficient to permit attainment of visual task performance rates equivalent to 90 per cent of their individual capacities by most persons with normal or corrected-to-normal vision.

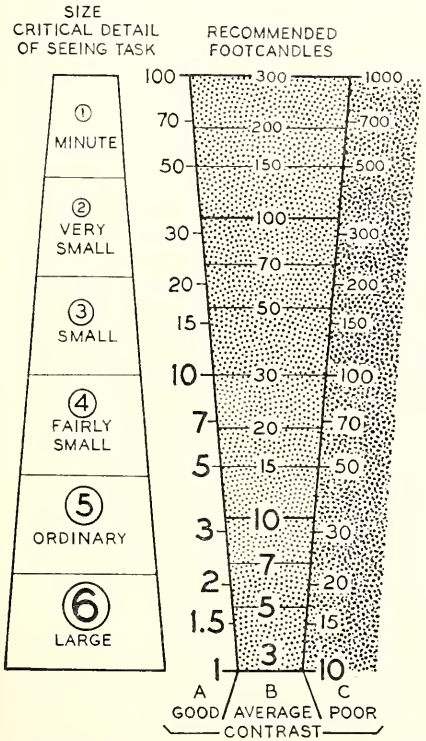


FIG. 2-10. Scale A gives recommended illumination values (British practice) for high contrasting backgrounds.[16] Scale B gives recommended values for average contrast tasks. Scale C gives recommended values for low contrast tasks such as sewing with black thread on dark cloth. The following values of the ratio D/S (usual viewing distance $D \div$ dimension of detail S) correspond to the steps on the size scale:

[4,100–3,200 minute] [3,200–2,450 very small] [2,450–1,900 small] [1,900–1,500 fairly small] [1,500–1,150 ordinary] [1,150–850 large].

One step higher on the foot-candle scale is recommended (British practice) when the objects are in motion and two steps if the task is also of long duration. The relative sizes of type suggest the type of installation: **10**—General lighting, **100** General or general plus local lighting, **1000**—Local supplementing general lighting.

Figure 2-10, taken directly from the British code, was developed from laboratory data of the type shown in Fig. 2-11. These were obtained from standardized performance tests (location of the gap in an international test object, black on white) conducted in laboratory cubicles under ideal conditions.[18]

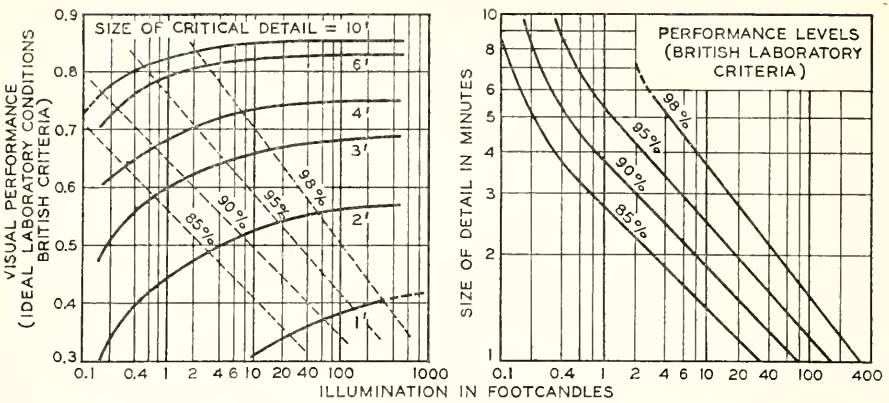


FIG. 2-11. The relationship between visual performance (discrimination of black international test objects on white) and illumination.[18]

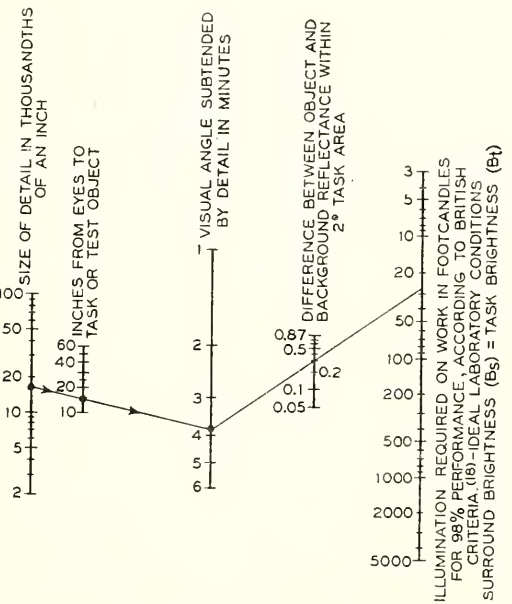


FIG. 2-12. Nomograph designed to give footcandles required for 98 per cent performance (British criterion) when the size of detail and reflectance of object and background are known.

To obtain the footcandles recommended by the British for a percentage perfomance between 90 and 100, for object-background contrasts less than 100 per cent, multiply the 100-per-cent contrast value for the percentage performance in question by $\frac{1}{\rho_1 - \rho_2}$, where ρ_1 is the reflectance of the background and ρ_2 is the reflectance of the object or detail. The results are accurate in the 95 to 100 per cent performance range and are approximately true for performance as low as 90 per cent.

Using Fig. 2-12 the footcandles required for 98 per cent performance may be obtained:

First, measure the critical size of the detail to be seen, the distance from the eyes, and the reflectance of the detail and its background. Then by plotting these values on the nomogram and drawing straight lines point to point (left to right), the footcandles required are found.

These values represent 98 per cent of maximum performance by unfatigued, young observers with normal or corrected-to-normal eyes, by maximum exertion, in ideally lighted cubicles, free from any hindering influences. It is good engineering practice to provide a safety factor, especially when it is expedient to depart from the ideal test conditions of the laboratory.

Note: For equal acuity the eyes of people around 60 years old (though normal for that age) require about twice the illumination required by the eyes of 20-year-olds. (See Fig. 2-13.) The handicap of persons with visual deficiencies decreases as the illumination is increased.

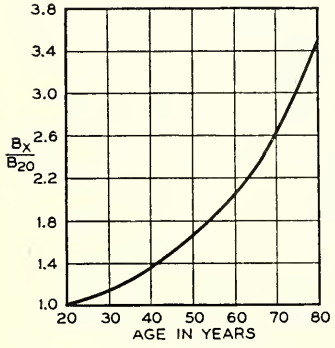


FIG. 2-13. Because of the reduction in pupil size which accompanies advancing age, higher brightnesses are required for equivalent effect in eyes of older observers. B_x = brightness at x years as compared with brightness (B_{20}) at 20 years.

Recommended American Interior-Lighting Practices

Judged against the British criteria, current American practice[19] appears to permit achievement of a better performance rating than might be expected under the British code.

Visibility based upon size, contrast, and brightness. As a means of measuring visibility it has been proposed that the visibility of a series of twenty standard black-on-white parallel-bar test objects (Fig. 2-4*A*), each of which subtends a visual angle in the series 1, 2, 3,—20 minutes, be reduced to threshold by means of a graduated density neutral filter.[20] The density necessary to reduce each test object to threshold is assumed to represent the relative visibility of that object above threshold.

A *visibility meter* operating on this principle is available. (See Fig. 2-14*A*.) Two identical filters, one for each eye, are provided in this

visibility meter. Both filters are calibrated, one in numbers (1–20) representing the size (minutes) of the test object reduced to threshold during calibration by each setting of the filter, and the other in recommended footcandles.

The footcandle scale is calibrated arbitrarily on the assumption that 10 footcandles is a conservative illumination for reading 8-point (3.7 minute size) black Bodoni type on white paper. For normal eyes the visibility of this reading task under 10 footcandles is chosen as a conservative standard by the designers. The user of the meter may, if he wishes, choose another standard (20 footcandles for example) and multiply scale readings by the new standard divided by 10 (scale reading × 20/10).

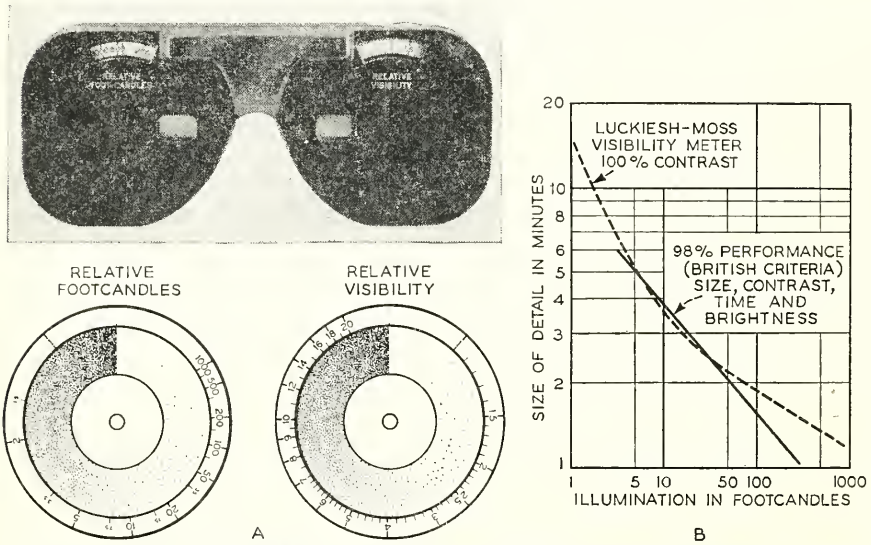


FIG. 2-14*A*. Luckiesh-Moss visibility meter showing graduated density filters. *B*. Comparison of footcandle recommendations obtained from a nomograph (Fig. 2–12) and by means of the Luckiesh-Moss visibility meter.

When the background brightness equals that used in calibrating the meter (usually 8 footlamberts) the observer by adjusting the filters so that the visibility of a new task is reduced to threshold may equate the task visibility to that of a standard test object under the recommended value of illumination. In Fig. 2-14*B* the footcandles required for the 98 per cent performance obtained using the nomogram (Fig. 2-12) are compared with the footcandles obtained with this visibility meter.

Age and Subnormal Vision

There is a general degeneration of bodily functions with age. The reduction in visual acuity is shown by Fig. 2-15. Pupil size decreases with age as shown in Table 2-2.

Table 2-2. Diameter of the Pupil in Millimeters[22]

AGE	IN DAYLIGHT	AT NIGHT	DIFFERENCE
20	4.7	8.0	3.3
30	4.3	7.0	2.7
40	3.9	6.0	2.1
50	3.5	5.0	1.5
60	3.1	4.1	1.0
70	2.7	3.2	0.5
80	2.3	2.5	0.2

The *Stiles-Crawford effect* is the reduced effectiveness of the rays of light entering the pupil at increasing distances from the center. The effect is not strong enough, however, to compensate for the reduction in pupil size with age, which makes it necessary to increase brightness (Fig. 2-13) if the same acuity, minimum perceptible contrast, and speed are to be maintained as an observer's age increases.[23]

Accommodation is the adjustment of the focal length of the eye for viewing objects at different distances. Upon tensing of the ciliary muscles, the lens bulges (Fig. 2-16*A*) to the proper contour to focus upon near objects.

The youthful eye tends to be flexible and therefore can focus upon very close objects (at eight years to 3 inches or less).

Age tends to stiffen the lens capsule in its flattened shape to the extent that the muscles are no longer able to give it the convex contour necessary for close vision. (See Fig. 2-16*B*.)

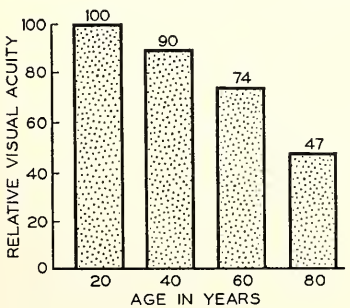


FIG. 2-15. The reduction of visual acuity with age.[21]

An *emmetrope* is a person with normal vision. *Presbyopia* is the term applied to loss of accommodation. A *myope* is one who is near sighted and cannot accommodate for far vision without correction.

The amplitude of accommodation for these types of vision is improved by an increase of illumination on the task. (See Fig. 2-16*B*.) The percentage of improvement is greatest for the presbyopes, and they also benefit much more in percentage gain of visual acuity. (See Fig. 2-16*B*.)

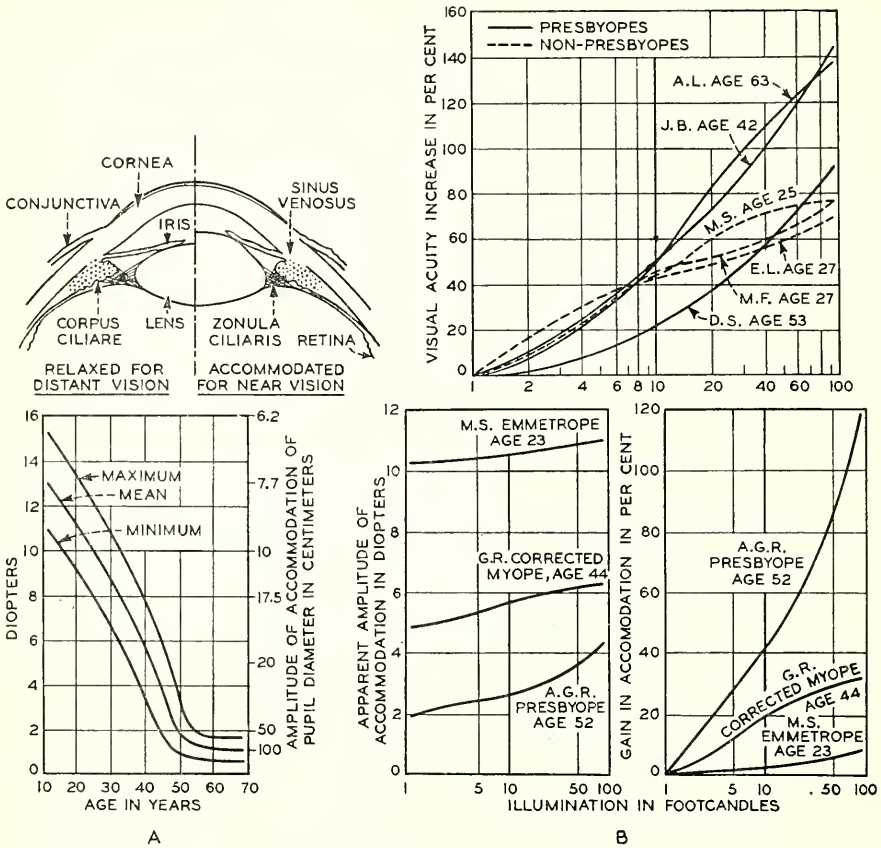


FIG. 2-16*A*. To adjust the curvature of the lens for focusing on near objects, the ciliary muscles are tensed, causing the lens to bulge. As the lens capsule stiffens with age the amplitude of this accommodation decreases as indicated by Duane's curves of norms of accommodation. *B*. Improvement in accommodation and acuity with illumination is greater for presbyopes than for emmetropes or myopes.

Glare

Everyone has experienced visual sensations caused by brightness relationships in the field of view. If the conditions interfere with vision, a layman may describe the phenomenon objectively as veiling or perhaps as blinding glare. If the sensation is strong and unpleasant, he may use the subjective terms uncomfortable, annoying, or intolerable.

Because visual efficiency and comfort are the prime objectives of all utilitarian and of many decorative lighting designs, glare which interferes with seeing or causes discomfort is a serious defect. Glare is avoided or eliminated whenever possible. Although much has been said which might

lead one to believe that there is an important difference between direct and reflected glare, if the results are evaluated in terms of the brightness viewed by the observer, it is not necessary to state whether the brightness is of a glare source viewed directly or of its reflected image.

Although it may often be possible to modify a lighting design so as to eliminate glare, even after the design has been carried out in a practical installation, usually it is simpler and less expensive to avoid the defect in the original design. For this reason illuminating engineers are working to develop satisfactory preinstallation methods of evaluating design brightness relationships with respect to their potential glare effect.

However, glare involves physiological and psychological as well as physical factors, and to determine the true relationship between the many variables under all practical conditions is a formidable task.

Despite the fact that a completely satisfactory solution is not in sight, several useful theories having individual merit have been proposed. However, because each of the theories is subject to some justifiable criticism, glare is considered a controversial subject and the theories should be applied carefully.

Though the desirability of judging glare phenomena against *disability* and *discomfort* criteria (distinct and unrelated in concept) has been agreed upon, and the utility of the Holladay-Stiles formula for evaluating disability glare has been recognized, no similar agreement has been reached on a method of evaluating discomfort glare.

The following convenient definitions, though not standard, serve to increase the precision achievable in glare discussions. Unless otherwise qualified the intended meaning in this handbook is that defined.

Adaptation level (B_A)—that brightness of a perfectly uniform field which would result in the same state of adaptation as the practical field of view in question.

Task (*t*)—the 2-degree area imaged on the fovea which includes the object or detail to be seen and the contrasting *background*.

Surround (*s*)—all of the field of view not occupied by the task.

Field of view (*f*)—comprises two monocular fields represented by two solid angles approximately 90 degrees wide and 120 degrees high that combine to form an approximately circular binocular field subtending about 120 degrees. (See Fig. 2-21, pg. 2-26.)

Glare source (*g*)—any brightness in the field of view which causes either visual disability or a sensation of discomfort.

Disability Glare

Disability-glare sources, by increasing an observer's adaptation level, reduce his contrast sensitivity or the contrast between a visual task and its background, or both. The same effect is observed if a veiling brightness is superposed uniformly on a task and background.[24]

Case 1: Uniform Field—Task Brightness Equals Surround Brightness. Disability glare is present whenever a source of higher brightness than that of the task is superposed on the surround. The observer's initial adaptation level equals the task brightness, and his new adaptation level (glare effect included) equals the sum of the original level and the equivalent veiling brightness.

The value of the equivalent veiling brightness for one or more glare sources ($B_g > B_t$) may be obtained from the following equation:

$$EVB = \frac{10\,\pi E_1}{\theta_1^2} + \frac{10\,\pi E_2}{\theta_2^2} + \frac{10\,\pi E_n}{\theta_n^2}$$

(See references 24 and 32.)

where EVB = veiling brightness equivalent in effect to one or more glare sources (footlamberts)

E_1, E_2, E_n = illumination on a plane through the observer's eye ($\perp$ line of sight) contributed by each glare source (footcandles)

$\theta_1, \theta_2, \theta_n$ = angle between the line from each glare source to the task and the observer's line of sight (degrees)

The observer's new adaptation level (glare effect included) is:

$$B_A = B_a + EVB \text{ (Holladay-Stiles formula)}^{26}$$

where B_a = the observer's initial adaptation level (glare effect neglected) = the task brightness B_t.

It appears that foveal adaptation for a uniform field is 90 per cent dependent on the brightness of the portion of the field imaged on the fovea, the surround contributing only 10 per cent of the total effect.[25] (See Fig. 2-18, $K = 0$.)

Case 2: Nonuniform Field—Task Brightness Greater than Surround Brightness. Disability glare is present whenever the observer's new adaptation level B_A (glare effect included) is greater than task brightness B_t. However, when the task is brighter than the surround, potential glare sources ($B_g > B_s$) may sometimes be superposed on the surround without causing disability glare.

The initial adaptation level B_a (potential glare effect neglected) may be determined by direct measurement or by computation.[25] It is a function of task brightness B_t and surround brightness B_s and perhaps also of a brightness B_{s_1} superposed on the surround. It will equal the contributions of the several field brightnesses integrated with respect to the angles by which their positions are displaced from the line of sight.[25]

To determine if disability glare is present, the equivalent veiling brightness may be found by using the equation:

$$EVB = \frac{10\pi E_1}{\theta_1^2} + \frac{10\pi E_2}{\theta_2^2} + \frac{10\pi E_n}{\theta_n^2}$$

Then the new adaptation level is:

$$B_A = B_a + EVB$$

and *disability glare exists whenever* $B_A > B_t$.

For the special situation shown in Fig. 2-17 in which the task is centered on a surround of 115 degrees diameter and brightness B_s on which is superposed a concentric annular area of brightness B_{s_1} such that $B_s + B_{s_1} = B_t$, and of variable outside radius θ, curves of B_A/B_t versus θ are plotted in Fig. 2-18 for several values of B_s/B_t .

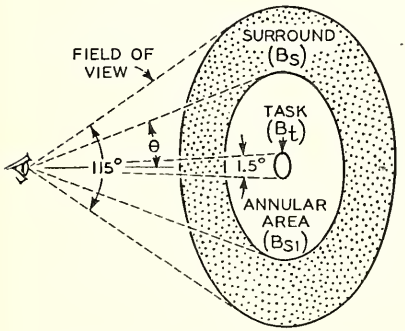


FIG. 2-17. One and one half degree task (brightness B_t) viewed against 115-degree surround (brightness B_s) on which is superposed an annular area ($O.D.$ = 2 θ, $I.D.$ = 1.5°) of brightness $B_{s_1} = B_t - B_s$. The variation $\frac{\text{adaptation brightness}}{\text{task brightness}}$ (B_a/B_t) with variation in θ is shown in Fig. 2-18.

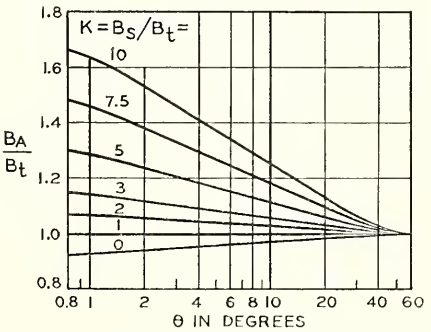


FIG. 2-18. Variation in the ratio (adaptation brightness, B_a/task brightness, B_t) with changes in angle θ for several values of k (equals surround brightness, B_s/task brightness, B_t) in the field shown in Fig. 2-17.

The magnitude of the disability-glare effect on contrast sensitivity may be determined for any situation as follows:

1. From Fig. 2-7 obtain the minimum perceptible contrast corresponding to the value of B_A.
2. Substitute the minimum perceptible contrast in the equation for C_{min} on page 2-9.
3. Solve for $(B_1 - B_2)$, $(B_1 = B_A)$.
4. The contrast sensitivity under glare condition will equal $\frac{B_a}{(B_1 - B_2)}$.

It has been found convenient to express the relationship between B_A and B_t as a surround factor:

$$\Lambda = \frac{B_A}{B_t}$$

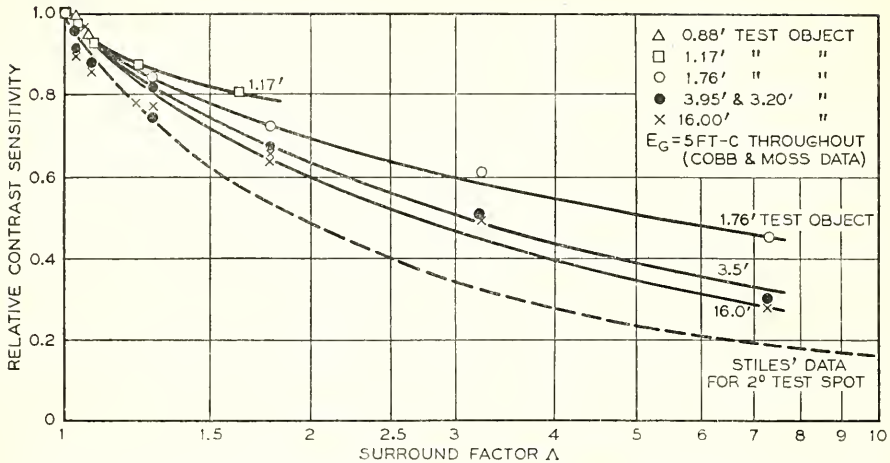


FIG. 2-19. Variation in contrast sensitivity with changes in surround factor ($A = B_A/B_t$) for several sizes of test objects.

Relative contrast sensitivity for various surround factors is plotted for several test objects in Fig. 2-19.

Discomfort Glare

The sensation experienced by an observer when brightness relationships in the field of view cause discomfort but do not necessarily interfere with seeing is known as the discomfort-glare effect.

Lacking a standardized procedure for evaluating this effect, five contemporary theories are presented; each has merit and in composite they represent the state of the art. With care and with an understanding of their individual limitations an experienced engineer may apply these theories advantageously to the solution of practical problems.

1. *Shock concept.* It is known that discomfort may be experienced when an observer adapted to one brightness level suddenly encounters the higher brightness of a potential-glare source.

It has been proposed[26] that the following empirical formula be used to determine the maximum brightness of a potential-glare source which may be viewed suddenly without discomfort:

$$B_g = \frac{KB_a^{0.3}}{\omega^{0.25}}$$

where

B_g = maximum comfortable brightness of a potential glare source (footlamberts)

K = 75.4 (sometimes called the index of comfort)

B_a = initial brightness level to which the observer was adapted immediately prior to encountering the potential glare source (footlamberts)

ω = solid angle subtended by the potential-glare source, which is assumed to be the circular area centered on the axis of fixation (steradians)

Table 2-3. Comfort-Discomfort Threshold Brightness of Various Common Luminaires in Different Rooms

LUMINAIRE	LAMP	BRIGHTNESS OF LUMINAIRE (ft-L)	SIZE OF ROOM IN FEET, NUMBER OF LUMINAIRES, HEIGHT OF LUMINAIRE					
			12 x 12 x 8 One 6.5 feet		30 x 30 x 12 Nine 10 feet		50 x 50 x 12 Twenty-five 10 feet	
			Illumination Level (ft-c*)	Threshold Brightness (ft-L)	Illumination Level (ft-c*)	Threshold Brightness (ft-L)	Illumination Level (ft-c*)	Threshold Brightness (ft-L)
FILAMENT-LAMP LUMINAIRES								
12″ Diffusing sphere	150-watt	750	7.3	315	12.8	570	14.8	570
14″ " "	200	785	10.2	325	18.2	590	21.0	595
16″ " "	300	955	15.9	355	29.0	640	33.6	645
18″ " "	500	1280	27.8	400	49.1	715	57.0	730
14″ Semi-indirect	200	370	8.0	315	14.7	570	17.0	600
16″ " "	300	455	13.2	345	23.4	625	27.2	650
18″ " "	500	610	23.0	390	39.6	690	46.0	715
16″ Luminous indirect	200	180	7.0	285	12.8	535	15.7	540
18″ " "	300	225	11.2	310	20.4	545	25	590
18″ " "	500	380	19.0	360	34.5	630	42.3	685
20″ " "	750	445	27.5	390	50.1	670	61.4	740
20″ " "	1000	645	39.9	435	72.5	740	89	825
FLUORESCENT-LAMP LUMINAIRES								
10″ x 4′ Half cyl Diffusing	two 40-watt	220	9.6	290	16.4	490	18.9	495
	four 40	440	19.2	360	32.8	610	37.8	620
12″ x 4′ Half cyl Diffusing	two 40	185	9.6	275	16.4	470	18.9	475
	four 40	370	19.2	345	32.8	590	37.8	595
14″ x 4′ Half cyl Diffusing	two 40	160	9.6	270	16.4	455	18.9	455
	four 40	320	19.2	335	32.8	570	37.8	570
10″ x 4′ Half cyl Semi-indirect	two 40	115	8.7	280	15.3	475	17.7	485
	four 40	230	17.5	350	30.7	590	35.4	610
12″ x 4′ Half cyl Semi-indirect	two 40	95	8.7	270	15.3	455	17.7	460
	four 40	190	17.5	335	30.7	565	35.4	580
14″ x 4′ Half cyl Semi-indirect	two 40	80	8.7	260	15.3	440	17.7	445
	four 40	160	17.5	325	30.7	540	35.4	560

* ft-c = footcandles on work of about 80 per cent diffuse reflectance. These footcandle values must be multiplied by 10 if the work has a diffuse reflectance of 8 per cent, by 4 if the work has a diffuse reflectance of 20 per cent, and so on.

When the brightness of the potential glare source is known its value may be substituted for B_g and the formula solved for K, the index of comfort. Values of B_g which result in values of K greater than 75.4 cause discomfort which becomes "intolerable" when $K = 377$; the smaller the value of K below 75.4, the smaller the probability that encountering the potential-glare source will cause discomfort. Since a shock is the cause,

it is conceivable that the sensation may be of short duration. The exact duration will be determined in each case by the complex relationship of the variables in the adaptation process.

Since it has been suggested that a series of discomfort shocks may have a cumulative fatigue effect (though each may seem instantaneous and of little consequence), it is believed desirable to apply a safety factor of 0.5 to threshold values. Threshold values (no safety factor, $K = 75.4$) for several types and numbers of sources in typical rooms are tabulated in Table 2-3. In preparing Table 2-3, methods of evaluating the contributions to the glare effect of all sources in the field, in addition to that fixated, were applied.[27]

2. *Glare ratings.* The following method of rating a lighting plan or installation with respect to its direct-discomfort-glare effect has been proposed.[23]

The basic assumptions are as follows:

First, the line of sight of the observer is horizontal.

Second, the unit of discomfort is the effect produced by a glare source with the following characteristics:

Area = 1 square inch
Location = 10 feet from the eye, 10 degrees above the line of sight
Brightness = 1,000 footlamberts, when the surround brightness against which it is viewed equals 10 footlamberts.

The glare factor for a single potential glare source is determined by the following empirical formula:

$$K = \frac{A\ B^2}{D^2\ \theta^2\ S^{0.6}} = \frac{I^2}{5AD^2\ \theta^2\ S^{0.6}}$$

where

K = glare factor for single source
A = apparent area of source (square inches)
B = brightness of source $\left(\frac{\text{footlamberts}}{1{,}000}\right)$
D = distance from source to eye $\left(\frac{\text{feet}}{10}\right)$
θ = angle between horizontal and line above it from eye to source $\left(\frac{\text{degrees}}{10}\right)$
S = surround brightness $\left(\frac{\text{footlamberts}}{10}\right)$
I = intensity of source in direction of the eye (candlepower)

If there are numbers of potential-glare sources in the field of view, a

composite-glare rating may be obtained by adding together the factor for each individual source.

In offices, drafting rooms, school rooms, and similar locations *glare ratings of less than 15 are considered to indicate comfort on the basis of the exponents used in the equation.* In factories, stores, and so on it is considered that a higher glare rating may be permissible.

3. *Photochemical theory applied to brightness ratios.* It has been proposed that discomfort glare be evaluated on a scale of comfortable brightness ratios derived from a modified photochemical theory of vision.[7, 29]

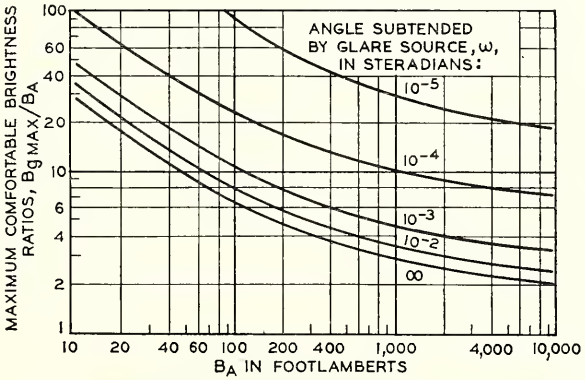


FIG. 2-20. Maximum comfortable brightness ratios ($B_{g\,max}/B_a$) for various adaptation levels, B_a, and sizes of glare source, ω.

In Fig. 2-20 are plotted comfort threshold brightness ratio curves obtained by substituting different values of B_a and ω in the following equation:

$$\frac{B_{g\,MAX}}{B_a} = \frac{(B/B_a)_\infty}{\omega}\,[0.00874 + \sqrt{\omega}]^2$$

where

$B_{g\,MAX}$ = maximum comfortable brightness of potential glare source (footlamberts)

B_a = observer's initial adaptation level (footlamberts)

$(B/B_a)_\infty$ = comfortable brightness ratio for a very large source

ω = solid angle subtended by potential glare source (steradians)

To determine if a potential glare source will cause discomfort, find the adaptation level B_a, the brightness of the potential glare source B_g, and the solid angle ω subtended by the source.

All values of B_g/B_a which fall below a horizontal line through the intersection of the B_a ordinate and the proper ω value curve will be comfortable, all those above will cause discomfort.

4. *Evolution and glare.* Evidence supports the belief that human eyes have developed through the ages to satisfy the needs of the natural human environment. Results of recent research indicate that man's normal habitat, based on the probability of his survival in the natural state (no clothes or shelter), is limited to the zone of the earth's surface covered by a 70-degree-Fahrenheit isotherm.

On the assumption that the eyes have been prepared through the evolutionary process to function properly under the conditions of this zone, comfortable flux ratios characteristic of the zone have been studied for guidance in interior-lighting design.

Based on an analysis of these data, Fig. 2-21 has been developed to suggest the comfortable limits of flux distribution ratios in the field of view.[30]

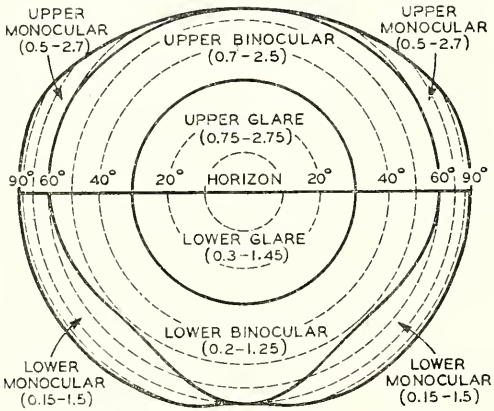


FIG. 2-21. Zonal limits of comfortable flux distribution ratios.

To determine if a lighting design or installation conforms to the criteria of comfort established by nature, the ratio of flux per unit solid angle in each zone of the field of view to the average flux per unit solid angle throughout the field is plotted in Fig. 2-21.

To obtain the ratios, a true perspective or a photograph is prepared on which the zones of the field of view may be laid out in scale. Then the flux per unit solid angle in each zone and in the field may be obtained by dividing the integral of flux from all sources in a given zone by the solid angle subtended by that zone.

5. *Spatial brightness equilibrium.* On assumptions similar to those just stated, another investigator has selected for analysis those natural scenes which immediately prior to sunset provide illumination of the order of 50 to 100 footcandles. This illumination may be provided indoors by means of available light sources, and electric power supply and distribution systems. It is suggested that comfort in this range will be assured if "spatial brightness equilibrium" comparable with that of the presunset period out of doors is maintained.[31]

Direct Glare and Reflected Glare

It is sometimes convenient to indicate by the terms *direct glare* or *reflected glare* whether the glare effect is caused by the brightness of a glare source itself, or by its reflected image. (See Fig. 2-22.)

Case 1: Both Object and Remaining Area of 2 Degree Task Have Perfectly Diffuse Surfaces. Contrast between the detail and its background is independent of the orientation of the observer and the sources contributing to the brightness of the task. (Fig. 2-23*A*.) *Disability and discomfort glare criteria may be applied equally well to all brightnesses in the field of view*, whether they are viewed directly or by reflection.

Case 2: Object and Task Have Other Than Perfectly Diffuse Surfaces. Contrast between the detail and its background is a function of the ob-

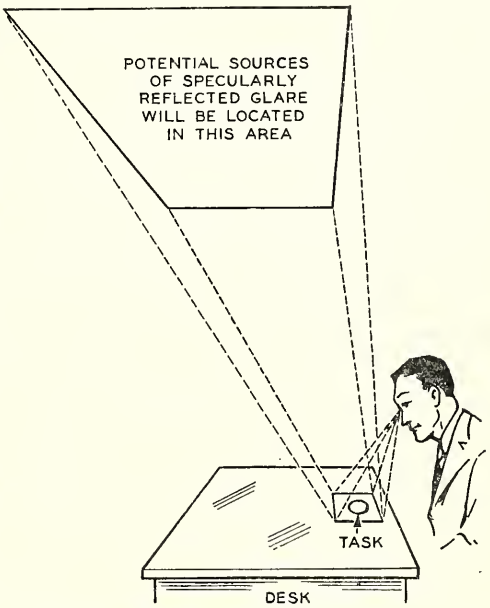


FIG. 2-22. Method for determining zone in which potential glare sources may be located.

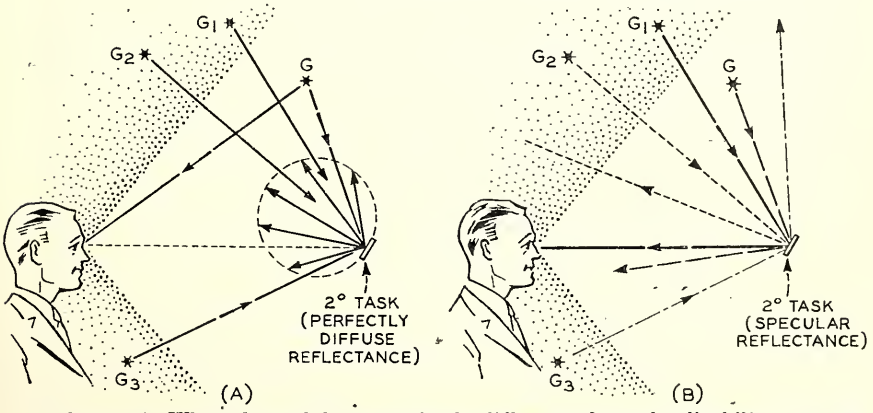


FIG. 2-23*A*. When the task has a perfectly diffuse surface, the disability and discomfort criteria applied to sources such as G in the field of view may be applied equally well to any source such as G_1, G_2, G_3, outside the field of view which contributes to the brightness of the task by reflection. *B*. When the task surface is specular the criteria may also be applied to sources outside the field of view, but only when the angle formed by eye and source with apex on the task is bisected by a normal to the task, as in the case of G_1.

server's position and of the orientation of sources contributing to the brightness of the task as viewed by the observer (Fig. 2-23*B*).[32] Contrast must be computed separately for each orientation of contributing sources and observer and *disability and discomfort criteria may be applied only to those sources which do not contribute to the apparent task brightness viewed by the observer.*

Visibility of Luminous Signals

Seeing luminous signals of the type projected by coastal lighthouses, airway beacons, and auto traffic lights involves the same factors of vision—size, background brightness, time, and color contrast—which are known to be important in other seeing problems.

For experimental convenience in the laboratory, many tests are run to determine the *visual threshold for a given task.* Large safety factors are usually required when laboratory threshold data are applied to practical seeing tasks.[33]

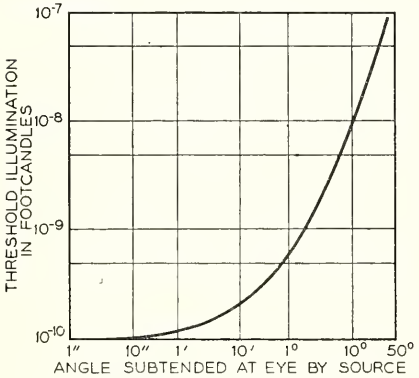


FIG. 2-24. Threshold illumination required at the eye for seeing circular objects of different sizes (dark background).[33]

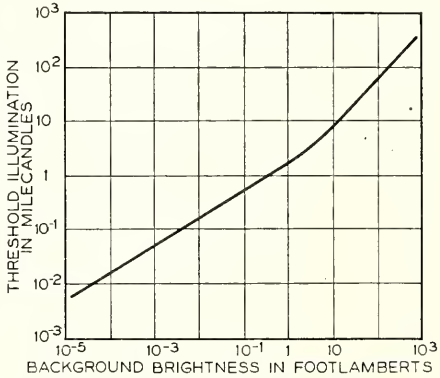


FIG. 2-25. Threshold illumination required at the eye for seeing point sources viewed against backgrounds of different brightnesses.[33]

Size. For threshold visibility, a large source must produce greater illumination at the eye than a small one. This relationship for circular areas is shown in Fig. 2-24. Luminous signals may usually be considered to be "point" sources.

Background brightness. The visibility of a point source is a function of the brightness of the background and surround, as shown in Fig. 2-25. Both contrast and the observer's adaptation level affect the threshold brightness.[34]

Time. For threshold visibility, the illumination at the eye produced by a flashing source must be greater than that produced by a steady source. The relationship is given by the equation:

$$\frac{E}{E_0} = \frac{t+a}{t}$$

where
E_0 = threshold illumination at the eye for a steady source (footcandles)
E = threshold illumination at the eye for a flashing source (footcandles)
t = duration of the flash (seconds)
a = 0.21 second

Note: It is assumed that the observer knows the location of the source and is looking toward it.

If it is necessary to locate a flashing light of a known brightness (above threshold) when its approximate position is not known, the time consumed in searching for it is a function of its brightness and flash duration and of the area searched.[33] This is expressed:

$$t = T\,(\phi/S - \tfrac{1}{2})$$

where
t = average search time before finding source (seconds)
T = duration of cycle (flash duration + dark period in seconds)
ϕ = solid angle subtended by the area searched (steradians)
S = external solid angle corresponding to retinal area for which the illumination produced by the source is above threshold (steradians)

Color contrast. When it is necessary to recognize correctly which color of a multicolor signal system is viewed, the illumination produced at the eye must be greater than that required for merely detecting the presence of the same source. Usually the more complicated the system the higher the threshold for each color: to provide positive recognition of each color of a three-color system requires more illumination at the eye than that required for positive recognition of each color in a two-color system but not as much illumination as required from each color of a four- or five-color system.

The individual spectral distribution characteristics of each color used in a system and their relationships also influence the value of illumination required at the recognition threshold. A system of colors of nonoverlapped spectral distributions with steep slopes requires less illumination at the recognition threshold than a similar system with overlapping spectral distributions of gradual slope.

Because small changes in atmospheric conditions as well as in spectral distributions cause appreciable differences in the illumination required at the threshold of recognition, great care must be taken in applying any experimental data to new problems.[35]

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SECTION 3

STANDARDS, NOMENCLATURE, ABBREVIATIONS, AND SYMBOLS

Among the hundred or more national professional and trade organizations engaged in standardization[1] in the United States, at least four[2] sponsor this work as their major activity. These co-operate with many other groups active in special fields, such as the Illuminating Engineering Society, and with state and federal governments. Their activities are reported in the monthly, *Industrial Standardization*, which is published by the American Standards Association. New lighting practices appear in *Illuminating Engineering*, the monthly publication of the Illuminating Engineering Society.

When a recommended practice or standard code[3] proposed by a professional group involves the safety or welfare of the general public, it is sometimes incorporated by the state legislatures in the state law. (See the index or Sections 15 through 16 of the Application Division for condensed forms of the codes recommended by the Illuminating Engineering Society.)

Because of American membership in various international groups, which comprise representatives of different nations, standardization in the United States is given international significance. The International Commission on Illumination, I.C.I. (*Commission Internationale de l'Eclairage*, C.I.E.), is the international organization concerned with illumination.

1. Reference Standards

The ability to measure physical quantities accurately is essential to progress in all phases of science and engineering. A fundamental step in developing this ability is the establishment of reference standards against which practical measuring tools may be calibrated.

When such standards are physical objects, they are customarily preserved at the National Bureau of Standards in Washington. An example is the set of carbon-filament lamps which has served as the American candlepower standard since 1909. Whenever possible, it is present practice to replace such arbitrary physical objects, which might never be exactly duplicated if destroyed, with standards suited to convenient and accurate reproduction in laboratories throughout the world.

Standard. A *primary standard* is one by which a unit of measurement is established and from which the values of other standards are derived. A satisfactory primary standard must be reproducible from specifications.

A *secondary standard* is calibrated by comparison with a primary standard.

A *working standard* is any calibrated tool for daily use in measurement work.

Note: References are listed at the end of each section.

Wavelength. The red cadmium spectrum line (0.64384696 micron in vacuum) has been established as the reference standard for all units of length.

Velocity. The velocity (c) of all radiant energy, including light, is $(2.99776 \pm 0.00004) \times 10^8$ meters per second in vacuum[4] (approximately 186,000 miles per second). In all material mediums the velocity is less and varies with the material's index of refraction and with wavelength.

Candlepower. In the United States, the candle (unit of luminous intensity) equals (0.05857) times the average horizontal candlepower of the standard group of forty-five carbon-filament lamps preserved at the Bureau of Standards. Within the limits of uncertainty of measurement, this is identical with the international candle adopted in 1909. Each lamp is operated at a voltage which results in a practical color match within the group at approximately 2,097 Kelvin color temperature.

In 1937, the International Committee on Weights and Measures adopted as the standard a blackbody operating at the temperature of freezing platinum. Its brightness was assigned the value of 60 candles per square centimeter. Candlepower values for standards having different spectral distributions may be obtained by the application of the luminosity factors (Table 1-3). This standard has not yet (1947) replaced the international candle adopted in 1909 by introduction into actual practice. The brightness of the new standard in terms of the 1909 unit is 58.9 candles per square centimeter.

Luminosity. Since the 1924 agreement of the I.C.I., Table 1-3 has been accepted internationally as representing the relative luminosity of the radiation of the wavelengths between 0.38 and 0.76 micron.

2. American War Standards Relating to Color

Various data related to color are included with some explanatory discussion in Section 4.

During World War II an American War Standard (ASA Z-44-1942) was developed to meet the recognized need for a method of describing and specifying color.[5,6,7,8,9,10,11,12,13,14,15,16] A Safety Color Code for marking hazards and identifying equipment (ASA Z-53.1-1945) was developed also.[17]

3. Standard Illuminants

By international agreement in 1931 the I.C.I. adopted the trichromatic system for mathematical color specification and established as standards for colorimetry the illuminants A, B, and C. The relative energy distributions of these illuminants are given in Table 3-1.

The following specifications are for practical laboratory sources which have the distribution characteristics of the standard illuminants:[8]

Illuminant A is a tungsten lamp operated at 2,848 K color temperature. However, for purposes of computation the data for a blackbody at 2,848 K are used ($c_2 = 14{,}350$ micron-degrees).

Illuminants B and C consist of illuminant A plus a filter. Illuminant B approximates a blackbody source operating at 4,800 K; it is used by the British as their daylight standard. Illuminant C approximates daylight provided by the combination of direct sun and clear sky light having a color temperature of approximately 6,500 K. The filters are made as follows:

For illuminant B, the filter consists of a layer one centimeter thick of each of the following solutions, contained in a double cell constructed of white optical glass:

No. 1	Copper sulphate ($CuSO_4 \cdot 5H_2O$)	2.452 g
	Mannite ($C_6H_8(OH)_6$)	2.452 g
	Pyridine (C_5H_5N)	30.0 cu cm
	Distilled water to make	1000.0 cu cm
No. 2	Cobalt-ammonium sulphate ($CoSO_4 \cdot (NH_4)_2SO_4 \cdot 6H_2O$)	21.71 g
	Copper sulphate ($CuSO_4 \cdot 5H_2O$)	16.11 g
	Sulphuric acid (density 1.835)	10.0 cu cm
	Distilled water to make	1000.0 cu cm

For Illuminant C, an identical cell is used, but the solutions are:

No. 1	Copper sulphate ($CuSO_4 \cdot 5H_2O$)	3.412 g
	Mannite ($C_6H_8(OH)_6$)	3.412 g
	Pyridine (C_5H_5N)	30.0 cu cm
	Distilled water to make	1000.0 cu cm
No. 2	Cobalt-ammonium sulphate ($CoSO_4 \cdot (NH_4)_2SO_4 \cdot 6H_2O$)	30.580 g
	Copper sulphate ($CuSO_4 \cdot 5H_2O$)	22.520 g
	Sulphuric acid (density 1.835)	10.0 cu cm
	Distilled water to make	1000.0 cu cm

Table 3-1. Relative Energy Distribution of Illuminants A, B, and C

WAVE-LENGTH (micron)	RELATIVE ENERGY			WAVE-LENGTH (micron)	RELATIVE ENERGY		
	A	B	C		A	B	C
0.380	9.79	22.40	33.00	0.580	114.44	101.00	97.80
.390	12.09	31.30	47.40	.590	121.73	99.20	93.20
.400	14.71	41.30	63.30	.600	129.04	98.00	89.70
.410	17.68	52.10	80.60	.610	136.34	98.50	88.40
.420	21.00	63.20	98.10	.620	143.62	99.70	88.10
.430	24.67	73.10	112.40	.630	150.83	101.00	88.00
.440	28.70	80.80	121.50	.640	157.98	102.20	87.80
.450	33.09	85.40	124.00	.650	165.03	103.90	88.20
.460	37.82	88.30	123.10	.660	171.96	105.00	87.90
.470	42.87	92.00	123.80	.670	178.77	104.90	86.30
.480	48.25	95.20	123.90	.680	185.43	103.90	84.00
.490	53.91	96.50	120.70	.690	191.93	101.60	80.20
.500	59.86	94.20	112.10	.700	198.26	99.10	76.30
.510	66.06	90.70	102.30	.710	204.41	96.20	72.40
.520	72.50	89.50	96.90	.720	210.36	92.90	68.30
.530	79.13	92.20	98.00	.730	216.12	89.40	64.40
.540	85.95	96.90	102.10	.740	221.66	86.90	61.50
.550	92.91	101.00	105.20	.750	227.00	85.20	59.20
.560	100.00	102.80	105.30	.760	232.11	84.70	58.10
.570	107.18	102.60	102.30				

Nomenclature

The precision required in the solution of engineering problems makes it necessary that both the oral and written language used by engineers in transmitting their ideas be precise. The standardization of terms and their proper use is therefore encouraged.

The Illuminating Engineering Society has had a technical committee engaged in the development of the standard nomenclature of its field for more than thirty years. The report of this committee, *Illuminating Engineering Nomenclature and Photometric Standards*, adopted by the society in *1941* and approved in *1942* by the American Standards Association as ASA Z7-1942, is the most recent of many revisions published since the first appeared in *1910*.

Because of inherent limitations of the standard nomenclature it has been proposed from time to time that a completely different nomenclature more conveniently related to other scientific terms and with greater generality and international utility be adopted.[18] However, a language develops largely as a result of usage, and because of their far-reaching influence, changes in standard nomenclature are made very cautiously. See Table 3-2.

Table 3-2. Standard Units, Symbols, and Defining Equations for Fundamental Quantities

QUANTITY	UNITS	ABBREVIATIONS	SYMBOLS	DEFINING EQUATIONS
		RADIATION—RADIOMETRY		
Radiant energy	erg joule calorie	 j cal	U	
Radiant energy density	erg per cubic centimeter	erg cm^{-3}	u	$u = dU/dV$
Spectral radiant energy	erg joule calorie } per micron	erg μ^{-1} $j\mu^{-1}$ cal μ^{-1}	U_λ	$U_\lambda = dU/d\lambda$
Radiant flux	erg per second **watt*	erg sec^{-1} w	Φ $*P$	$\Phi = dU/dt$
Radiant flux density or radiancy **Radiant emittance*	watt per square centimeter **Watt per square meter*	w cm^{-2} w m^{-2}	W	$W = d\Phi/dA$
Irradiancy **Irradiance*	watt per square centimeter **watt per square meter*	w cm^{-2} w m^{-2}	H	$H = d\Phi/dA$
Radiant intensity	watt per steradian	W ω^{-1}	J	$J = d\Phi/d\omega$
Spectral radiant intensity	watt per steradian per micron	W $\omega^{-1}\mu^{-1}$	J_λ	$J_\lambda = dJ/d\lambda$
Steradiancy **Radiance*	watt per steradian per square centimeter **watt per steradian per square meter*	W ω^{-1} cm^{-2} W ω^{-1} m^{-2}	N	$N = dJ/(dA \cos\theta)$ θ = angle between line of sight and normal to surface considered

Table 3-2 continued:

QUANTITY	UNITS	ABBREVIATIONS	SYMBOLS	DEFINING EQUATIONS
		LIGHTING—PHOTOMETRY		
Luminosity factor	lumen per watt	lm watt^{-1}	K	$K = F_\lambda/\Phi_\lambda$
Luminous flux †*pharos*	lumen **lumerg/sec* †*lumen*	lm †lm	F †F	
Quantity of light **luminous energy* **talbot*	lumen-hour	lm-hr *lm-sec	Q	$Q = \int F dt$ (t in hrs)
†*phos*	†*lumen-second*	†lm-sec	†Q	†$Q = \int F dt$ (t in sec)
†*phosage*	†*lumen-second per square meter*	†lm-sec m^{-2}	†W	†$W = 1/A \int F dt$ (t in sec)
Illumination **Illuminance* †*pharosage*	footcandles lux phot †*lumens per square meter*	ft-c lx ph †lm m^{-2}	E E †D	$E = dF/dA$ (A = area of surface illuminated) †$D = dF/dA$
Luminous intensity or candlepower	candle	c	I	$I = dF/d\omega$ (ω = solid angle through which flux from point source is radiated)
Brightness **Luminance* †*Helios* †*Heliosent*	candles per unit area stilb apostilb lambert footlambert apparent footcandle †*blondel* †*blondel per meter*	c/in^2 sb lm m^{-2} L ft-L †bl †bl m^{-1}	B B' †H †G	$B = dI(dA \cos\theta)$ (θ = angle between line of sight and normal to surface considered) $B' = \pi dI(dA \cos\theta)$ †$H = \pi(dD/d\omega)\cos\psi$ (ω = solid angle ψ = angle of incidence of central ray) †$G = dH/dr$ (r = distance along central ray)

* Proposed by the Colorimetry Committee of the *O.S.A.* (nonstandard).[18]
† Proposed by Moon (nonstandard).[18]

Except where indicated the following material has been revised and condensed for handbook publication from the standard nomenclature. The three subdivisions immediately following, on radiation, light, and light measurement, deal with *fundamental concepts.*

1. Radiation Terms

Radiant energy travels in the form of electromagnetic waves.

Radiant energy density is radiant energy per unit volume.

Spectral radiant energy is radiant energy per unit wavelength interval $\Delta\lambda$, at wavelength λ.

Radiant flux is the time rate of flow of radiant energy.

Radiant flux density is the ratio of radiant flux at an element of surface to the area of the element.

Steradiancy in a given direction is the radiant flux per unit solid angle, per unit of projected area of the source viewed from that direction.

Irradiancy is the incident radiant flux per unit area.

Radiant intensity is the radiant energy emitted per unit time, per unit solid angle about the direction considered.

Spectral radiant intensity is radiant intensity per unit wavelength interval.

2. Terms Relating to Light

Light, for the purposes of illuminating engineering, is radiant energy evaluated according to its capacity to produce visual sensation. The evaluation is accomplished by multiplying the energy radiated at each wavelength by the standard luminosity factor for that wavelength and adding the results: $F = \int_{0.38}^{0.76} K_\lambda J_\lambda d\lambda$. See Table 1-3.

Luminous flux is the time rate of flow of light.

Illumination is the density of luminous flux incident upon a surface. It equals the quotient of flux by the area of the surface when the flux is uniform over the area.

Luminous intensity is the solid angular luminous flux density in the direction in question. It equals the quotient of the flux on an element of surface by the angle subtended by the element when it is viewed from the source.

Brightness is the luminous intensity of any surface in a given direction, per unit of projected area of the surface viewed from that direction.

3. Basic Units of Light Measurement

The **lumen** is the unit of luminous flux. It equals the flux emitted through a unit solid angle (one steradian) from a point source of one candle.

The **lumen-hour** is the unit of light. It is the quantity of light delivered in one hour by a flux of one lumen.

The **footcandle** is the unit of illumination when the foot is the unit of length. It is the illumination on a surface, one square foot in area, on which is uniformly distributed a flux of one lumen. It equals lumens per square foot. See Fig. 3-1.

The *lux* is the unit of illumination in the metric system. It equals lumens per square meter.

The *phot* is the unit of illumination when the centimeter is the unit of length. It equals lumens per square centimeter.

The **candle** is the unit of luminous intensity.

Candlepower is luminous intensity expressed in candles.

The *apparent candlepower* of an extended source (at a specified distance) is the candlepower of a point source which would produce the same illumination at that distance.

The *mean spherical candlepower* of a lamp is the average candlepower of the lamp in all directions in space. It is equal to the total luminous flux (lumens) of the lamp divided by 4π.

The *mean horizontal candlepower* of a lamp is the average candlepower in the horizontal plane passing through the geometrical center of the luminous volume of the source. It is assumed that the axis of symmetry of the source is vertical.

The **footlambert** is the unit of brightness equal to the average brightness of any surface emitting or reflecting one lumen per square foot. It equals $1/\pi$ candle per square foot. This is also called the apparent footcandle.

The *lambert* is the unit of brightness equal to the average brightness of any surface emitting or reflecting one lumen per square centimeter. It equals $1/\pi$ candle per square centimeter.

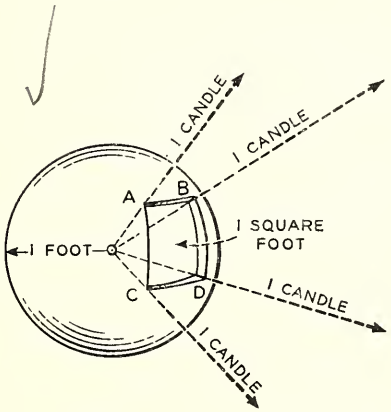


FIG. 3-1. Relationship between candles, lumens, and footcandles.

A uniform point source (luminous intensity or candlepower = 1 candle) is shown at the center of a sphere of 1 foot radius. It is assumed that the sphere is perfectly transparent (i.e., has 0 reflectance).

The illumination at any point on the sphere is 1 footcandle (1 lumen per square foot).

The solid angle subtended by the area, A, B, C, D is 1 steradian. The flux density is therefore 1 lumen per steradian, which corresponds to a luminous intensity of 1 candle, as originally assumed.

The sphere has a total area of 12.57 (4π) square feet, and there is a luminous flux of 1 lumen falling on each square foot. Thus the source provides a total of 12.57 lumens.

4. General Terms in Illumination

angstrom: a unit of length equal to 10^{-8} (one one-hundred-millionth) centimeter.

micron: a unit of length equal to 10^{-4} (one ten-thousandth) centimeter.

x-unit: a unit of length equal to 10^{-11} (one one-hundred-thousandth-millionth) centimeter.

mega: a prefix meaning *one million* (10^{6}).

kilo: a prefix meaning *one thousand* (10^{3}).

milli: a prefix meaning *one one-thousandth of* (10^{-3}).

micro: a prefix meaning *one one-millionth of* (10^{-6}).

temperature radiator:* a radiator the radiant flux density (radiancy) of which is determined by its temperature and the material and character of its surface, and is independent of its previous history.

blackbody:* a temperature radiator of which the radiant flux in all parts of the spectrum is the maximum obtainable from any temperature radiator operating at the same temperature; will absorb all radiant energy falling upon it; practically realized in the form of a cavity with opaque

* See Pages 1-8 and 1-12.

walls at uniform temperature and with a small opening for observation purposes.

graybody:* a temperature radiator the spectral emissivity of which is less than unity and the same at all wavelengths.

total emissivity* (e_t): the ratio of the radiant flux density (radiancy) at an element of any temperature radiator to that at an element of a blackbody at the same temperature.

spectral emissivity* (e_λ): the ratio at a given wavelength of the radiant flux density per unit wavelength interval (at that wavelength) of any temperature radiator to that of a blackbody at the same temperature.

5. Lighting Terms

luminosity factor: the ratio of the luminous flux at a particular wavelength to the radiant flux at that wavelength. It is expressed in lumens per watt. The relative luminosity factor is a dimensionless ratio set equal to unity at 0.554 micron wavelength. Standard (relative) luminosity factors are given in Table 1-3.

luminous efficiency of radiant energy: the ratio of the total luminous flux to the total radiant flux (usually expressed in lumens per watt of radiant flux). For energy radiated at a single wave-length, luminous efficiency is synonymous with luminosity factor.

This term is not to be confused with the term *efficiency* as applied to a light source since the latter is based on the power *consumed* by the source instead of on the radiant flux from the source.

mechanical equivalent of light (minimum): the reciprocal of the luminous efficiency (maximum) of radiant energy; that is, the watts per lumen at the wavelength of maximum luminosity.

The best experimental value is 0.00154 watt per lumen, corresponding to 650 lumens per radiant watt, the maximum possible efficiency of a light source. When expressed in terms of the new value of the lumen these values become, respectively, 0.00151 watt per (new) lumen and 660 (new) lumens per watt. See page 1-12.

efficiency (of a light source): the ratio of the total luminous flux to the total power input, expressed in lumens per watt, or, (for combustion sources) in lumens per thermal unit consumed per unit of time.

reflection factor (reflectance) (ρ or r): the ratio of the light reflected by the body to the incident light.

transmission factor (transmittance) (τ or t): the ratio of the light transmitted by the body to the incident light.

performance curve: a curve representing the variation in performance of a lamp (candlepower, consumption, and so forth) during its life. See Fig. 6-39, page 6-43.

characteristic curve: a curve expressing a relationship between two variable characteristics of a source, such as candlepower and volts, candlepower and rate of fuel consumption, and so forth. See Fig. 6-10, page 6-11.

curve of light distribution: a curve showing the variation of luminous

* See pages 1-8 and 1-12.

intensity of a lamp or luminaire with angle of emission. See Fig. 5-9b, page 5-17.

solid of light distribution: a solid the surface of which is such that the radius vector from the origin to the surface in any direction is proportional to the luminous intensity of the light source in the corresponding direction.

isocandle line: a line plotted on any appropriate co-ordinates to show directions in space, about a source of light, in which the candlepower is the same. See Fig. 8-17, page 8-47.

isolux line: a line, plotted on any appropriate co-ordinates, showing points of equal illumination. See Fig. 8-20, page 8-49.

coefficient of utilization (of an illumination installation): the total flux received by the reference plane divided by the total flux from the lamps illuminating it. See Fig. 8-19, page 8-48. When not otherwise specified, the plane of reference is assumed to be a horizontal plane 30 inches (76 centimeters) above the floor. See Table 8-2.

lamp: a light source.

electric filament lamp: a light source consisting of a glass bulb containing filament electrically maintained at incandescence; commonly called an incandescent lamp, an electric light or a light bulb.

electric discharge lamp: a lamp in which light is produced by the passage of electricity through a metallic vapor or a gas such as mercury, sodium, neon, argon, and so forth, enclosed in a tube or bulb; sometimes called a vapor lamp.

luminaire: a complete lighting unit including lamp, globe, reflector, refractor, housing, and such support as is integral with the housing. The term *luminaire* is used to designate completely equipped lighting fixtures, wall brackets, portable lamps, and so forth which are removable. It does not include permanent parts of a building, such as a ceiling, or other structural element; in street-lighting units the pole, or bracket is not considered a part of the luminaire.

color: the characteristics of light other than spatial and temporal inhomogeneities.

Color of an object: the capacity of the object to modify the color of the light incident upon it.

Colorants: substances used to produce the color of an object.

Dominant wavelength (of a color): the wavelength that, combined with white light (equal energy spectrum) in suitable proportions, matches the color.

Complementary wavelength: the wavelength that, combined with a sample color in suitable proportions, matches white light is the sample's complementary wavelength.

Purity: The relative brightnesses* of the spectrum and white components in the mixtures obtained in making a color match determine and are specified by purity.

Colorimetric purity: the ratio of the brightness of the spectral component to the brightness of mixture obtained in making a color match.

* Candancy and luminance have been proposed as being more appropriate terms.

Excitation purity: the ratio of the distance from the white point to the point representing the sample to the distance along the same straight line from the white point to the spectrum locus or the purple boundary, both distances being measured on the I.C.I. chromaticity diagram.

Chromaticity: the characteristics of light specified by dominant wavelength and purity. (Complementary wavelength and purity for purples.)

Chromaticity diagram: a diagram on which chromaticities are represented by points independent of the choice of a standard quality white. See Fig. 4-6, page 4-12.

Spectrum locus: the locus of points representing the colors of the visible spectrum in a chromaticity diagram.

Purple boundary: the straight line drawn between the ends of the spectrum locus.

Blackbody locus: the locus of chromaticities of blackbodies having various temperatures.

Locus of whites: points in a region of a chromaticity diagram representing qualities that may be considered white under circumstances of common occurrence.

Three-color mixture: a mixture of suitable amounts of light of three suitably selected chromaticities with which a color may usually be matched.

Color-mixture data: the amounts of the primaries required to establish a match.

Transformation of color-mixture data: computations of color-mixture data for one set of primaries having data for another set.

Luminosity coefficients: constants the sum of whose multiples by the three-color mixture data for any color give the brightness* of the color.

Trichromatic coefficient: the ratio of any one of the color-mixture data for a sample to the sum of the three-color mixture data. $x = \frac{X}{X + Y + Z}$

Trichromatic co-ordinates: any pair of the trichromatic coefficients used as co-ordinates of a point in a plane representing the chromaticity of a sample (x, y).

I.C.I. standard illuminants for colorimetry: the three illuminants adopted by the I.C.I. for use in colorimetry are designated A, B, and C. Selected ordinates for Illuminants A, B, and C are given in Table A-13, page A-28.

Indirect colorimetry: color-mixture data for any sample computed from the data for the spectrum and the spectral distribution of the sample.

Selected ordinate method of colorimetric calculation: a method of avoiding the numerous multiplications of indirect colorimetry by summing the spectral distribution data for specially selected, nonuniformly spaced wavelengths. See pages 4-16 and A-24.

6. Ultraviolet Radiation Terms

erythemal flux: radiant flux evaluated according to its capacity to produce erythema (temporary reddening) of the untanned human skin.

* Candancy and luminance have been proposed as being more appropriate terms.

relative erythemal factor: a factor which gives the relative erythemal effectiveness of radiation of a particular wavelength as compared with that of wavelength 0.2967 micron, which is rated as unity.

unit of erythemal flux (E-viton, erytheme): an amount of radiant flux which will give the same erythemal effect as 10 microwatts of radiant energy at 0.2976 micron.

finsen: the recommended practical unit of erythemal flux density. It equals one unit of erythemal flux per square centimeter.

erythemal exposure: the product of erythemal flux density on a surface by the duration of the exposure. It equals the amount of effective radiant energy received per unit of area exposed.

7. Electrical Terms

There are two types of electric currents: *alternating* (*ac*) and *direct* (*dc*). By alternating current is meant a current which changes its direction of flow at regular intervals, and by direct current, one that continues to flow in one direction. The *frequency* of alternating current is the total number of times the current flows in each direction per second. Most alternating current in the United States has a frequency of 60 *cycles* per second.[19]

In an a-c circuit the alternation of the current is not always in step (in phase) with the voltage. If the current lags behind the voltage, the circuit is said to contain *inductance* and if the current *leads* the voltage, the circuit is said to have *capacitance*. *Reactance* is the general term that correctly designates both inductance and capacitance.

In an a-c circuit containing reactance, the power consumed is not given by the product of the voltage and current alone and thus cannot be determined from the measurement of the current and voltage but must be measured by a wattmeter. The ratio of the wattage to the product of the current and voltage is called the *power factor* of the circuit. For a circuit containing resistance only, the power factor is unity. For any other circuit the power factor is a proper fraction.

The phenomenon that occurs on making or breaking a circuit containing inductance or capacitance is called a *transient*. If a voltage is suddenly applied to a circuit containing capacitance, there is an initial rush of current exceeding the steady current which will be maintained by the same voltage, but when an inductive circuit is broken an electromotive force is developed which tends to cause the current to continue to flow.

electromotive force: the potential difference (pressure) measured in volts required to cause a *current* of electricity, measured in amperes, to flow through a *resistance*, measured in ohms.

fundamental units: the *ampere*, a unit defined as the current which will deposit 1.118 milligrams of silver per second in a voltameter under certain specified conditions; and the *ohm*, a unit equal to the resistance at 0C of a column of mercury 106.3 centimeters long of constant cross section and having a mass of 14.4521 grams.

watt: a unit of electric power equal to the power required to maintain a current of one ampere through a resistance of one ohm.

Abbreviations for Scientific and Engineering Terms[20]

A

absolute abs
alternating current (as noun) spell out or ac
alternating-current (as adjective) spell out or a-c
ampere amp
ampere-hour amp-hr
Angstrom unit A
antilogarithm antilog
atmosphere atm
atomic weight at. wt
avoirdupois advp
azimuth az or α

B

boiling point bp
British thermal unit Btu or B

C

calorie cal
candle c
candlepower cp
centimeter cm
centimeter-gram-second (system) cgs
chemically pure cp
circular mils cir mils
coefficient coef
cologarithm colog
conductivity cond
constant const
cosecant csc
cosine cos
cotangent cot
coulomb spell out
counter electromotive force cemf
cycles per second spell out or c

D

decibel db
degree deg or °
degree centigrade C
degree Fahrenheit F
degree Kelvin K
diameter diam
direct current (as noun) spell out or dc
direct-current (as adjective) spell out or d-c

E

efficiency eff
electric elec
electromotive force emf

F

farad spell out or f
feet per minute fpm
feet per second fps
foot ft
footcandle ft-c
footlambert ft-L
foot-pound-second (system) fps
freezing point fp
frequency spell out
fusion point fnp

G

greatest common divisor gcd

H

henry h
horsepower hp
horse-power-hour hp-hr
hour hr
hundred C

I

inch in.
inches per second ips
inside diameter ID

J

joule j

K

kilocalorie kcal
kilocycles per second kc
kilogram kg
kilometer km
kilometers per second kmps
kilovolt kv
kilovolt-ampere kva
kilowatt kw
kilowatthour kwhr

L

lambert L
latitude lat or ϕ
least common multiple lcm
logarithm (common) log
logarithm (natural) log or ln
longitude long. or λ
lumen lm

M

mass spell out
maximum max

mean horizontal candlepower	mhcp
megacycle	spell out
megohm	spell out
melting point	mp
mho	spell out
microampere	μ a or mu a
microfarad	μf
micromicrofarad	$\mu\mu$f
micron	μ or mu
microvolt	μv
microwatt	μw or mu w
mile	spell out
miles per hour	mph
milliampere	ma
milligram	mg
millihenry	mh
millimeter	mm
millimicron	mμ or m mu
minimum	min
minute	min
minute (angular measure)	′
molecular weight	mol. wt

N

National Electrical Code	NEC

O

ohm	spell out or Ω
ohm-centimeter	ohm-cm
outside diameter	OD

P

parts per million	ppm
per / (for tables, not recommended in text matter)	
potential	spell out
power factor	spell out or pf

R

radian	spell out
reactive kilovolt-ampere	kvar
reactive volt-ampere	var
revolutions per minute	rpm
revolutions per second	rps
root mean square	rms

S

secant	sec
second (angular measure)	″
sine	sin
specific gravity	sp gr
specific heat	sp ht
square	sq
square centimeter	sq cm or cm^2
square foot	sq ft
square inch	sq in.
square kilometer	sq km or km^2
square meter	sq m or m^2
square micron	sq μ or sq mu or μ^2
square millimeter	sq mm or mm^2

T

tangent	tan
temperature	temp
thousand	M

V

volt	v
volt-ampere	va
volt-coulomb	spell out

W

watt	w
watthour	whr
weight	wt

Y

yard	yd
year	yr

Common Symbols[21]

In technical literature many symbols are used to save space and for convenience in setting up equations. The following are common:

MATHEMATICS

+ plus	≈ nearly equal to	> greater than
− minus	≡ identical with	≯ not greater than
± plus or minus	≢ not identical with	< less than
× multiplied by	≎ equivalent	≮ not less than
÷ divided by	≏ difference between	: is to; ratio
= equal to	∼ difference	:: as; proportion
≠ not equal to	≅ congruent with	∺ geometric proportion

$\doteq$ approaches	$\pm$ equilateral	∞ infinity
$\rightarrow$ approaches limit of	$\measuredangle$ equiangular	$\int$ integral
$\propto$ varies as	$\surd$ radical; root; square root	$\mathcal{f}$ function
$\parallel$ parallel to	$\sqrt[3]{}$ cube root	∂ or δ differential; variation
$\perp$ perpendicular to	$\sqrt[4]{}$ fourth root	π pi
$\angle$ angle	Σ sum	$\therefore$ therefore
$\frown$ arc of circles	$\lfloor\!\lfloor$ product; factorial	$\because$ because

Physics and Chemistry

HP horsepower	$\mathcal{R}$ reluctance
$\triangle$ increment	$\rightarrow$ direction
Φ magnetic flux	$\leftrightarrows$ electrical current
Ψ dielectric flux; electrostatic flux	pH potential hydrogen
ρ resistivity	 benzene ring
γ conductivity	$\rightarrow$ yields
$\triangle$ equivalent conductivity	$\rightleftarrows$ reversible reaction
$\downarrow$ precipitate	$\uparrow$ gas

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20. *American Standard Abbreviations of Scientific and Engineering Terms*, ASA Z10.1-1941, American Standards Association, New York.

21. *Style Manual*, Current Edition U. S. Government Printing Office.

SECTION 4

COLOR

Colored light and colored surfaces may be produced, applied, perceived, and appreciated because of both their utility and decorative effect. Whether the primary objective is beauty or utility, the final result will almost always be a combination of some degree of both. Therefore it is desirable to give careful consideration to both the aesthetic and the functional phases of all problems involving color.

Various ramifications of color involve chemistry, physics, physiology, psychology, and fine arts, as well as good taste. Ordinarily the skills utilized in the development of decorative color schemes for products, packages, interiors, or exteriors are quite different from those required for the measurement and specification of color. Whereas the artist may be expected to create an aesthetically harmonious scheme, it remains for the physicist and the engineer by numerical specifications of colors to provide a certain and unambiguous means of translating the conceptions of the designer into production. It is also a technical problem to maintain production of the same color unchanged over a considerable period and in widely separated plants, and later to reproduce a color which has been out of production for a considerable time.

The illuminating engineer is concerned with color problems because light is an important factor related to the ultimate aesthetic and functional success of any color scheme. Also, the utility, appearance, and aesthetic effect of a lighting design may be influenced appreciably by the colors of surfaces in the illuminated area.

Because of the wide differences which exist between the immediate interests, experience, and training of individuals engaged in the several phases of color work, the possibility for misunderstanding between them is great. During World War II, the American Standards Association adopted an Emergency Standard, Z44-1942, in order to eliminate such misunderstanding and many wastefully divergent practices. This standard recommends a method of physical measurement (spectrophotometry) as the fundamental process in the standardization of color. (See page 4-24.) The standard also recommends the use of basic color specifications which can be computed from fundamental spectrophotometric data by a method adopted by the International Commission on Illumination. For the popular interpretation of these basic color specifications, which might otherwise be incomprehensible to most people, the Standard recommends the use of descriptive I.S.C.C.-N.B.S. color names, which can be determined from the basic color specifications, "wherever general comprehensibility is desired and precision is not important."

The I.S.C.C.-N.B.S. system of color names described on page 4-6 supplements the fundamental technical color terminology included in Section 3.

NOTE: References are listed at the end of each section.

It is not suggested that the I.S.C.C.-N.B.S. names will replace either the numerical specifications or the trade names which manufacturers of textiles, wall coverings, tiles, paint, and so forth, have been using conveniently for many years, but rather that they may assist in correlating and expediting all color work.

Color and Visual Performance

From a practical standpoint, when compared on an equal-lumen basis, colors of light emitted by common illuminants are about equally satisfactory for most seeing problems. Apparently the only major exception occurs when the seeing problem involves color discrimination. The color of light most effective for discriminating some surface colors is among the least effective for discriminating others. The increase and decrease of brightness contrasts between colored objects in consequence of differential increase and decrease of their luminous reflectance is the major effect of different illumination colors.[1] (See Color Grading, page 4-17.)

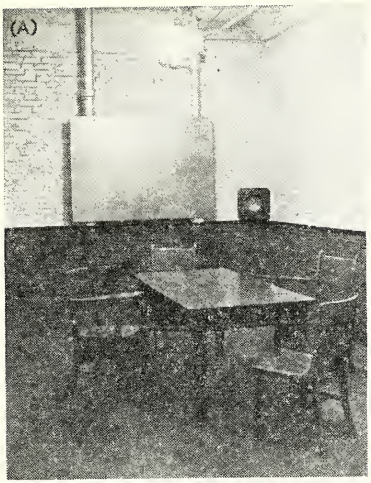
The color of walls, furniture, and other equipment seems to influence comfort and efficiency, but insufficient data are available to permit developing harmonious color combinations on a strictly engineering basis. Since taste and emotional reactions are involved in any evaluation of the results, it is probable that the solution of aesthetic design problems will continue to be based in good part on experience and judgment for some time, despite the existence of several proposals whereby solutions may be obtained through the application of mathematical formulas. (See page 4-16.)

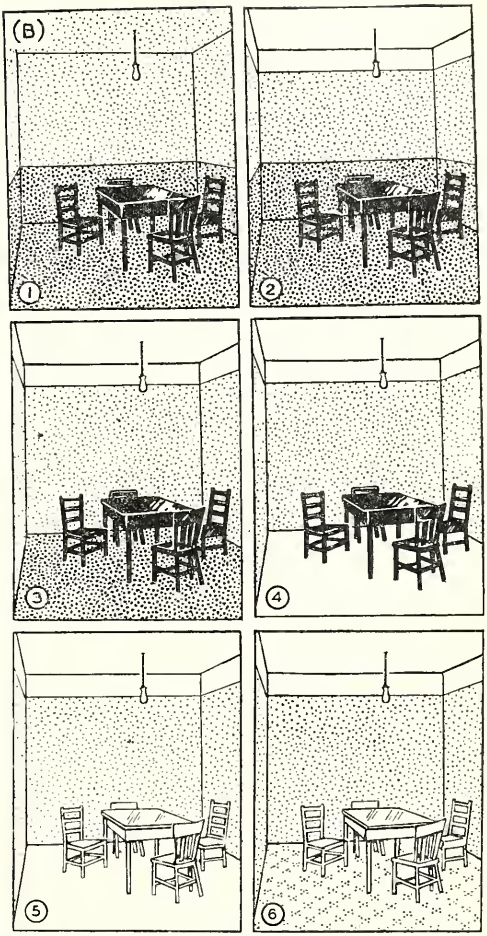
Color combinations and contrasts for working areas. The effects on seeing of contrast between task and background and of brightness and brightness distribution in the field of view are discussed in Section 2. However the data apply to tasks which for the most part involve black objects on white backgrounds. If it is desirable to have contrast but at the same time nearly uniform brightness in the field of view, color may be used.

Few studies have been made to determine the effect of the color and brightness of surrounding surfaces on the utilization of light for seeing.[2]

Surface colors and luminous reflectance. The luminous reflectances of surfaces vary with their color and with the light source used for illumination. Luminous reflectances are of major importance in lighting design since they influence brightness and flux distribution ratios, and illumination levels. The quantitive effects of the luminous reflectance and color of wall materials have been studied both by direct measurement and by mathematical analysis. It may be stated positively that light walls and ceilings, whether white or colored, are much more efficient than dark walls in conserving light and in distributing it uniformly.[3]

In Fig. 4-1, photographs of a room in an industrial building before and after interior modifications were made are shown with sketches which suggest the step by step changes in luminous reflectance and color scheme.[3] The results of these changes in terms of footcandles and utilization coefficients also are indicated.

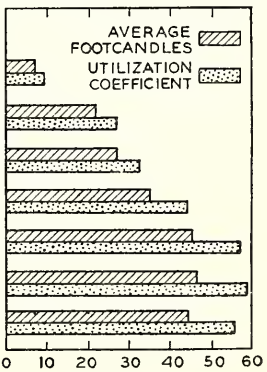






STEP	CEILING			WALLS		FLOOR		FURNITURE	
	HEIGHT	COLOR	R*	COLOR	R*	COLOR	R*	COLOR	R*
START	12 FT	WHITE	30	WHITE AND GRAY	40	DARK RED	12	DARK OAK	28
1	10 FT		65						
2	10 FT		85						
3	10 FT	CREAM	85	GREEN	72	WHITE	85	BLOND	50
4	10 FT		85						
5	10 FT		85						
6	10 FT		85			WHITE AND RUSSET	70		

* REFLECTANCE



(D)

FIG. 4-1. Effect of color scheme on appearance, coefficient of utilization, and illumination level in a small room in an industrial area.[3] (*A*) Test room before changes in color scheme. (*B*) Step by step changes. (*C*) Test room with light walls, ceiling, floor, and furniture. (*D*) Variation of illumination and utilization coefficient with color scheme.

The results of a mathematical analysis of the effect of wall colors on illumination and brightness ratios in cubical rooms, having white ceilings ($r = 0.80$), totally indirect lighting, and black floors ($r = 0.00$), are given in Fig. 4-2. An increase of wall reflectance by a factor of 9 may result in an increase of illumination by a factor of about 3. Although the walls in rooms having low ceilings as compared with their length and width exhibit less control than in cubical rooms, wall reflections exert an appreciable influence when the ratio of length to width to height is as great as 20:10:1.[4]

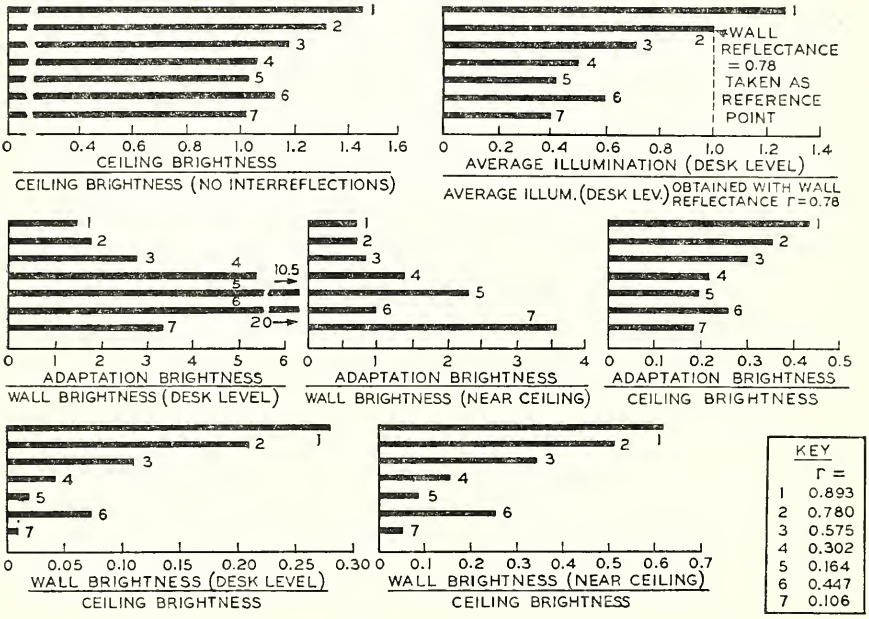


FIG. 4-2. Effect of wall colors on illumination and brightness ratios in a cubical room. (Neutral white ceiling $r = 0.80$; neutral black floor $r = 0.00$; totally indirect lighting.)[4] (*1*) White wallboard $r = 0.893$, (*2*) White asphalt tiles $r = 0.780$, (*3*) Cream washable fabric $r = 0.575$, (*4*) Cream asbestos board $r = 0.302$, (*5*) Gray asbestos board $r = 0.164$, (*6*) Primavera wood $r = 0.447$, (*7*) Walnut wood $r = 0.106$.

Hues versus neutral gray for wall surfaces. When a colored and a gray surface of equal luminous reflectance are equally illuminated with light direct from an illuminant they will be equally bright. However, if a considerable portion of the light reaching the working surface has undergone several reflections from troughs and walls, as is usually the case in indirect or semi-indirect lighting, greater illumination will be obtained if those surfaces are colored than if they are grays of the same luminous reflectance. The amount of this improvement is shown in Fig. 4-3 for yellow, blue-green, and pink walls in comparison with gray walls having the same luminous reflectances. The greater the number of inter-reflections, the greater is the advantage to be gained. In the case of the blue-green and

pink walls, when the light has suffered five successive reflections before reaching the work surface, as in an indirect system, the illumination may be twice as great as would be obtained with gray walls of equal luminous reflectance. The magnitude of this effect can be computed for any surface by multiplying the spectral reflectances at the selected ordinates by themselves as many times as the number of interreflections. In all cases, the average of these products will be greater if the reflectance varies throughout the spectrum than if it is constant (as in the case of a gray surface) at a value equal to the luminous reflectance of the surface color for the first reflection. The color of the light after numerous interreflections differs from the color of light direct from the source and is always such that the luminous reflectance of the colored walls is higher for it than for the color initially emitted by the lamps. If the walls are blue, then the light which has been reflected several times is more blue than that initially emitted by the illuminant.

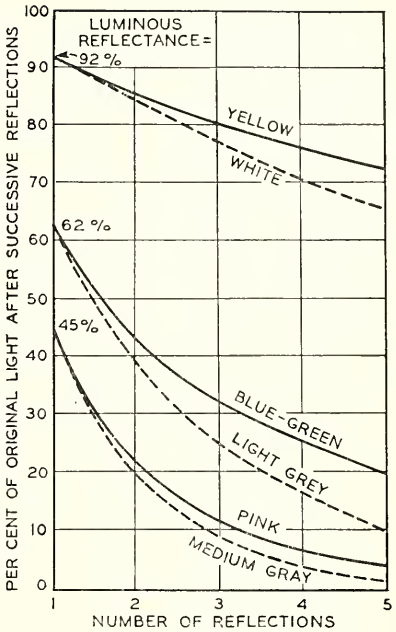


FIG. 4-3. Comparison of interreflection efficiencies of colored and neutral surfaces having the same luminous reflectance.

Color Names and Notations

The lack of precision characteristic of many terms used in everyday speech contributes to the difficulty encountered in preparing specifications which must be unambiguous and enforceable and yet at the same time understandable to a layman.

In some cases, the efficient statement of color specifications sufficiently precise to satisfy the layman requires the use of carefully defined but unfamiliar technical terms. Fortunately such precision is not always necessary and a simple system of color designation developed by the Inter-Society Color Council in co-operation with the National Bureau of Standards often will be found adequate.

The notation and charts of the Munsell and Ostwald systems are well known. In addition, there are many other collections of physical color samples in use which offer practical utility to persons who understand their principles and purpose.[6]

Webster's New International Dictionary: 150 samples in 1946 unabridged edition.

Dictionary of Color: Over 7,000 samples, with color names based on historical origins and current usage. By A. Maerz and M. Rea Paul. McGraw-Hill Book Company, New York.

Ridgway: About 1,000 samples, each identified by name, widely used by archaeologists and naturalists. Robert Ridgway, Washington, 1912.

Textile Color Card Association of the United States, Inc.: Issues standard and seasonal cards in dyed silk, the accepted authority in the textile industry. 200 Madison Avenue, New York.

Hiler Color Chart: 162 color samples showing mat and gloss finishes with card index box containing masks and matching apertures. Favor, Ruhl & Company, Chicago and New York.

Color Kit: Color identification achieved through the use of disks and a mechanical spinning device. Designed by Birren, The Crimson Press, Westport, Connecticut.

Nu-Hue Color Directory: Over 1,000 paint samples with convenient matching placques and precise mixing formulas for each. Any color can be purchased by the gallon at retail. Martin-Senour Company, Chicago.

Plochere Color Guide: Over 1,000 color samples, with paint mixing formulas for each. G. Plochere, 1820 Hyperion Avenue, Los Angeles.

American Colorist: Contains over 500 samples, widely used in horticulture, art, and industry. Developed by Birren, The Crimson Press, Westport, Connecticut.

I.S.C.C.-N.B.S. system of color designation. Known as the "Inter-Society Color Council—National Bureau of Standards System," this plan was approved by the Color Council in 1939 for use in the drug and chemical fields.[7] The designations are equally appropriate and useful for other applications, and it is likely that they will be adopted gradually for general use. The system provides 312 color names, each of which designates one block of the Munsell color solid. Munsell notations for the boundary colors of each block have been determined.[5] Spectrophotometric measurement of the spectral reflection characteristics of the standard Munsell color chips have been made and these data have been transposed into the I.C.I. co-ordinates for illuminant C (standard daylight). Therefore, it is convenient to convert a color name, having meaning to the layman, into Munsell notation having significance for the decorator, and into I.C.I. co-ordinates, which are familiar to the colorimetrist.

Standard names and hue abbreviations are given in Table 4-1. Central Munsell notations for each block are given in Appendix Table A-14, page A-29.

Since there are likely to be many distinguishable (though very similar) colors in each of the 312 Munsell blocks, the use of the names is limited in accuracy. If a more accurate specification is necessary, numerical notation (Munsell or I.C.I.) may be used.

The greatest accuracy and precision in color specification may be obtained through the intelligent use of spectrophotometric curves. This method is basic and is widely used in the United States, having been made a part of ASA Z44-1942.

Table 4-1. I.S.C.C.-N.B.S. Standard Hue Names and Abbreviations[7]

NOUN FORM	ABBREVIATION	ADJECTIVE FORM	ABBREVIATION	ADJECTIVE MODIFIER	ABBREVIATION
pink	Pk	pinkish	pk	light	lt
red	R	reddish	r	dark	dk
orange	O	orange	o	weak	wk
brown	Br	brownish	br	strong	str
yellow	Y	yellowish	y	moderate	mod
olive	Ol	olive	ol	medium	med
green	G	greenish	g	vivid	viv
blue	B	bluish	b		
purple	P	purplish	p	ADVERB MODIFIER	ABBREVIATION
white	Wh				
gray	Gr				
black	Bk			very	v

Capitalized abbreviations refer to the noun form, lower case signifies the adjective form.

Systems of Transparent Color Standards

Color specifications based upon transparent mediums take advantage of the fact that it is possible with a fixed illuminant to control the color of the transmitted light over a wide range by introducing varying amounts of three absorbing materials, permitting the light to pass through two or more elements of the absorbing medium instead of through a single element. The color specification consists of the number of unit elements of each of the three absorbing components required to produce the color match by subtractive combination.

The Lovibond system utilizes combinations of standardized glass filters of different thickness.[8, 10, 11, 12] The Army system utilizes combinations of standardized filter solutions of variable concentration.[13]

Such color systems are best suited to the specification of the color of other transparent mediums because it is usually easy to assure that standard and sample receive the same amount and kind of illumination. Under those circumstances departure from a standard illuminant usually produces only a second-order effect upon the color specification.[9]

Munsell and Ostwald Systems of Surface Color Designation

The color designation systems utilizing physical samples developed respectively by Albert H. Munsell, a Boston art teacher, and by Wilhelm Ostwald, a German, winner (1909) of the Nobel Prize in chemistry, are the two most widely known and used in the United States for designating surface colors. Each system is based on an orderly classification of opaque surface-color samples which lends itself readily to arrangement in the color solids shown in Fig. 4-4.

Munsell system. In the Munsell system, a color is designated according to its *value*, *chroma*, and *hue*. The color solid is divided along its vertical axis into equally perceptible *value* units; along radii into equally perceptible *chroma* units, and angularly into equally perceptible *hue* units.

Any value unit equals every other value unit and any chroma unit equals every other chroma unit, but in perceptibility, value units do not equal chroma or hue units except by chance. Hue units equal each other only for fixed levels of both value and chroma.[14]

The relationship between Munsell value units and reflectance is shown in Table 4-2. To convert from Munsell notation to I.C.I. co-ordinates, see page 4-14.

Table 4-2. Relationship between Munsell Value and Luminous Reflectance

MUNSELL VALUE	LUMINOUS REFLECTANCE (Relative to smoked layer of magnesium oxide*)	MUNSELL VALUE	LUMINOUS REFLECTANCE (Relative to smoked layer of magnesium oxide*)
10.0	102.6	7.8	55.6
9.9	100	7.7	53.9
9.8	97.4	7.6	52.3
9.7	94.9	7.5	50.7
9.6	92.4	7.4	49.1
9.5	90	7.3	47.5
9.4	87.7	7.2	46
9.3	85.3	7.1	44.5
9.2	83.1	7.0	43.1
9.1	80.8	6.5	36.2
9.0	78.7	6	30
8.9	76.5	5.5	24.6
8.8	74.4	5	19.8
8.7	72.4	4.5	15.6
8.6	70.4	4	12
8.5	68.4	3.5	9
8.4	66.5	3	6.55
8.3	64.6	2.5	4.6
8.2	62.7	2	3.1
8.1	60.9	1.5	2.0
8.0	59.1	1	1.2
7.9	57.4	0	0

*To obtain absolute luminous reflectance, multiply values given by 0.974.

The Munsell notation for any color is written in this order:

hue, value/chroma

The most common form of notation includes letters and whole numbers for hue, and whole numbers for value and chroma:

5R 4/10 is read "five red, four-ten."

Examination of Fig. 4-4 reveals that when compared with 5R 4/10,

4R 4/10 would be more purple

5R **5**/10 would be lighter (have higher luminous reflectance)

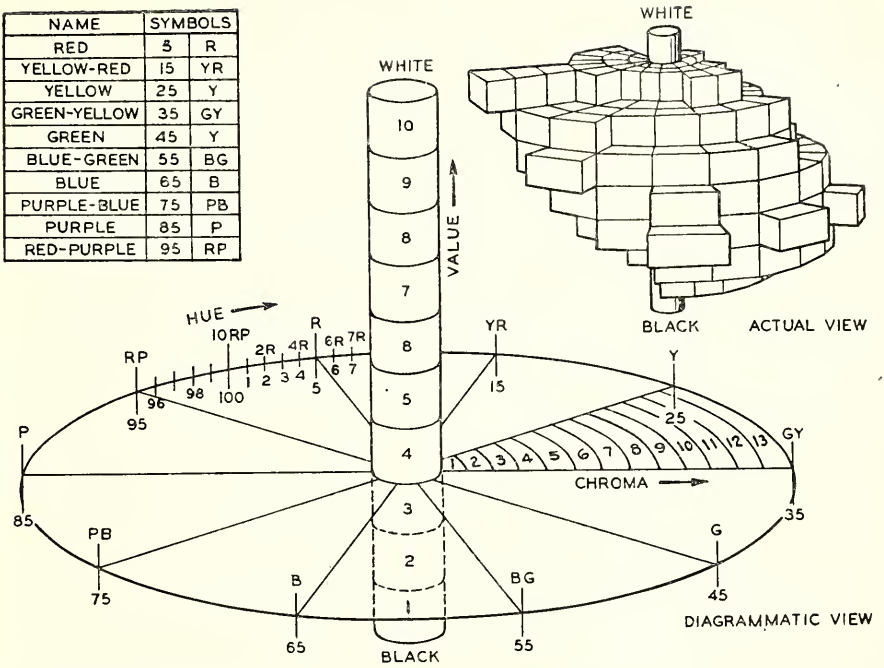
5R 4/**9** would be more neutral (gray).

For greater precision, decimals may be added:

5.1R 4.2/10.3 would be slightly more yellow, lighter, and more chromatic than 5R 4/10.

The hue letters and decimals may be avoided by using the 100-step hue scale shown in Fig. 4-4:

NAME	SYMBOLS	
RED	5	R
YELLOW-RED	15	YR
YELLOW	25	Y
GREEN-YELLOW	35	GY
GREEN	45	Y
BLUE-GREEN	55	BG
BLUE	65	B
PURPLE-BLUE	75	PB
PURPLE	85	P
RED-PURPLE	95	RP



NAME	SYMBOLS	
YELLOW	1	1Y
	2	2Y
	3	3Y
ORANGE	4	10
	5	20
	6	30
RED	7	1R
	8	2R
	9	3R
PURPLE	10	1P
	11	2P
	12	3P
ULTRA-MARINE BLUE	13	1UB
	14	2UB
	15	3UB
TURQUOISE	16	1T
	17	2T
	18	3T
SEA GREEN	19	1SG
	20	2SG
	21	3SG
LEAF GREEN	22	1LG
	23	2LG
	24	3LG

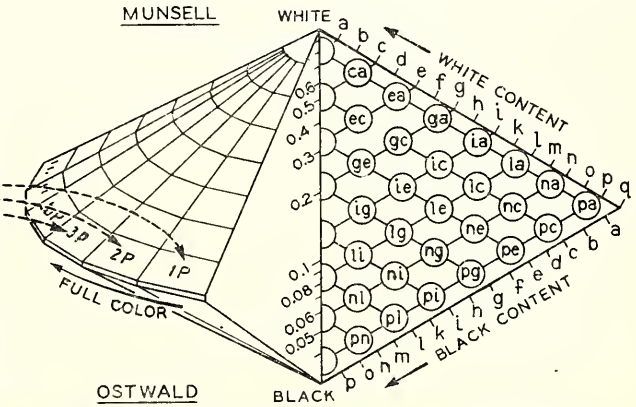


FIG. 4-4. Common forms of Munsell and Ostwald color solids showing notation scales by which colors are designated according to their position in the solid.[15]

5 4/10 is read "five, four-ten" and equals 5R 4/10.

95 4/10 is read "ninety-five, four-ten" and equals 5RP 4/10 read "five red-purple, four-ten."

Collections of carefully prepared and standardized color chips may be obtained in several different forms from the Munsell Color Company, Inc., 10 East Franklin Street, Baltimore 2, Maryland. Neither standard library nor pocket editions include the high-value illuminating-engineer's chips

(higher than 8/). However, standardized chips which include high values of neutral grays, low chroma reds, yellows, greens, blues, and purples are mounted in the pocket-size folder (Fig. 4-5), which has been developed especially for illuminating engineers. The chips in the folder are arranged for convenient comparison with surface colors. With practice in the use of this chart, value may be estimated rather accurately and converted to luminous reflectance by means of the scales provided. Inexpensive papers in colors designated in Munsell notation, suitable for everyday use though not sufficiently uniform for standards, are available.

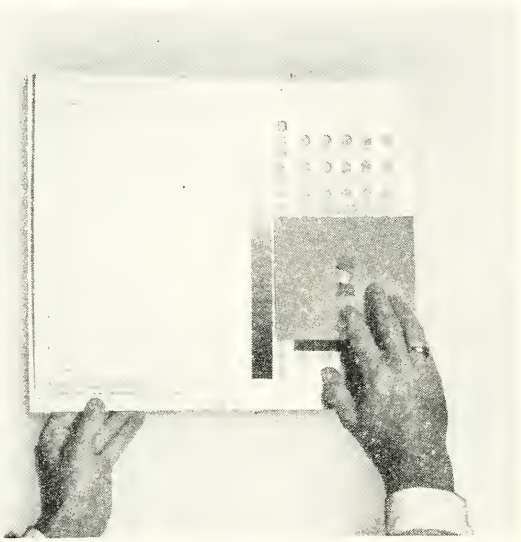


FIG. 4-5. Munsell chart, pierced for easy comparison with surface colors, permits quick estimate of luminous reflectance.

Luminous reflectance for the neutral grays, which are nonselective, is the same for all illuminants, but for colors of high chroma, it depends upon the illuminant. The reflectance of a yellow surface will be higher under a yellow illuminant than under a blue illuminant, and so on. Reflectances which may be expected for several colors of high chroma under different illuminants are given on page 164, *Iluminating Engineering*, March 1945.

Ostwald system. The Ostwald system of color order is presented in the Jacobson *Color Harmony Manual*, obtainable from the Container Corporation of America,. Inc., 111 West Washington Street, Chicago 2, Illinois. In this system a color is designated according to its white, black, and "full-color" content by means of a letter notation which signifies the position of the color in the Ostwald color solid (Fig. 4-4).

The notation for a color is written in the form:

ie8, which is read: "i, e, eight."

This specifies a pink or pastel red. Examination of Fig. 4-4 reveals that:

ie**7** would be more orange
ie**9** more purple
he8 would be less pure (more white)
ke8 more pure (less white)
id8 would be more pure (less black)
if8 less pure (more black)
ha8 would be lighter (higher luminous reflectance)
kf8 would be darker (lower luminous reflectance)

The solid is divided logarithmically along its vertical axis according to the Weber-Fechner law of equivalent sensation. Absolute white (luminous reflectance 100 per cent) is at the top of the scale and absolute black is at the bottom. It is also divided angularly into twenty-four "full-color" wedges, each of these represented by an equilateral triangle in a vertical plane through the axis covering an area of constant dominant wavelength.

Colors located in lines parallel to the vertical axis (isochromes) have constant purity; colors located in lines parallel to the bottom of the triangle (isotints) have constant white content; and colors located in lines parallel to the top of the wedge (isotones) have constant black content.

If the reflectance of any two or more Ostwald colors is equal, it is the result of chance rather than of planning. However, I.C.I. (x, y) co-ordinates for each chip in the Jacobson manual have been determined and the Ostwald notations for this set of chips may be transposed through the I.C.I. co-ordinates to Munsell notation or any other notation for which I.C.I. data are available. These I.C.I. co-ordinates are not applicable to any set of Ostwald chips[15] except those of the Jacobson manual.

Basic Systems of Color Specification

I.C.I. system. The I.C.I. standards for colorimetry consist of data representative of a normal (standard) observer and three standard illuminants (A, B, and C). The conditions of illuminating and viewing the test sample are specified as 45 degrees and 90 degrees respectively. In this system color is expressed in terms of three primaries.[16]

Results of any spectrophotometric measurement may be reduced to the terms of the I.C.I. observer and co-ordinate system. In I.C.I. form, the data are expressed as the absolute (X, Y, Z) and fractional (x, y, z) amounts of each primary which, for the standard observer, match a given sample under a given illuminant. The fractional values $x = \frac{X}{X + Y + Z}$ and $y = \frac{Y}{X + Y + Z}$ are called the trichromatic coefficients of a color. The value of luminous reflectance or transmittance (r or t) equals the Y value which carries all the luminosity. To avoid the use of negative numbers in specifications, the three primaries have been assigned mathematical characteristics which cannot be reproduced in any physical form, such as red, green, or blue lights. However, since the specifications may be used conveniently and the primaries need never be used, the theoretical character of the latter is not a practical obstacle.

In Appendix Table A-11, page A-26, the characteristics of the standard observer (Table 1-3, page 1-4) are combined with data for several light sources, ready for computational use in the manner indicated on page A-24.

Dominant wavelength, purity, and luminous reflectance. Dominant wavelength and purity are quantities which are more suggestive of the appearance of a color than the I.C.I. specifications, from which they may be determined in the manner indicated on page 4-14. They may also be found by direct measurement.[17] They specify the chromaticity of a color, and Figs. 4–6, 4–7, and 4–8 are chromaticity diagrams.

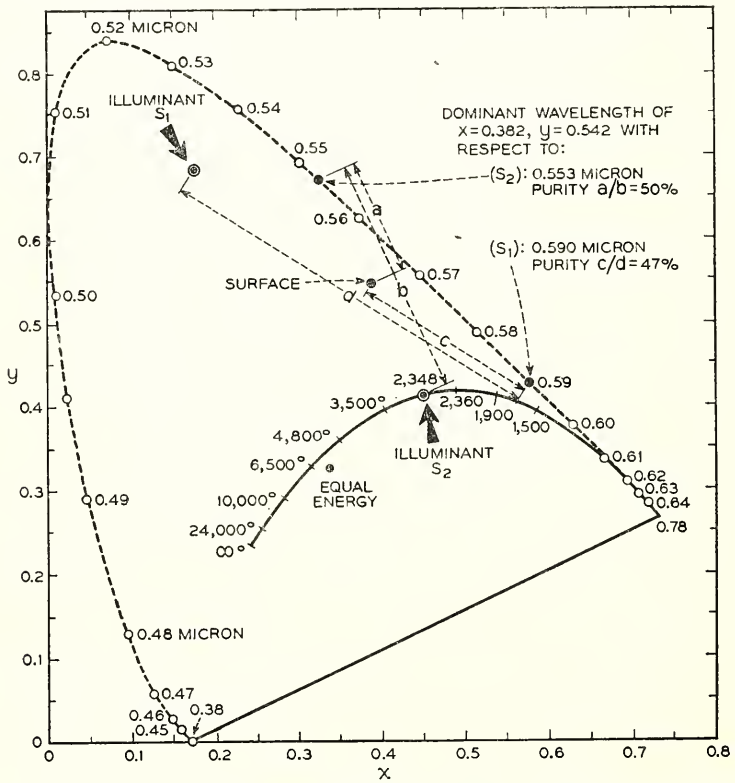


FIG. 4-6. Locus of spectrum colors plotted on a chromaticity diagram showing method of obtaining dominant wavelength and purity for different samples under different illuminants.

To obtain values by direct measurement,[17] a mixture is made of the amount of spectrum light of a homogeneous nature (single wavelength) and the amount of heterogeneous equal energy (neutral) light needed to match a given sample. The tristimulus coefficients for the equal energy spectrum are given in Appendix Table A-15, page A-34. The wavelength of the monochromatic spectrum light needed for a match is the dominant wavelength of the sample. The proportion of the spectrum light (per cent) in the mixture needed for a match under a given illuminant is the purity

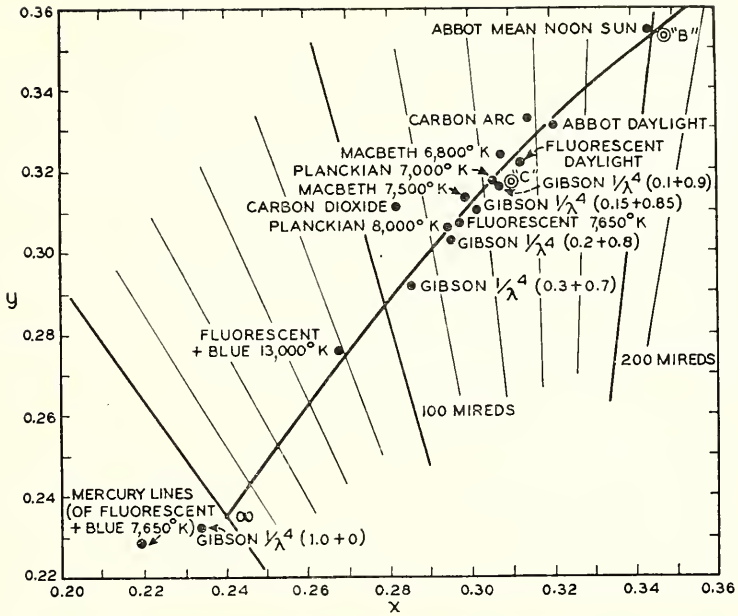


FIG. 4-7. Section of expanded scale chromaticity diagram showing Planckian locus and isotemperature lines for determining *nearest color temperature*. (Illum Eng., March, 1941)

of the sample (spectrum plus equal [neutral] energy = 100 per cent). Luminous reflectance may be determined by any method of heterochromatic photometry.

Color temperature. Color temperature describes the chromaticity of a completely radiating (blackbody) source and is widely used in illumination work. Such a body is black at room temperature (when it does not radiate any visible energy), red when heated to a temperature within 800 K to 900 K, yellow at about 3,000 K, white (neutral) at a temperature of 5,000 K, weak blue at a temperature between 8,000 K and 10,000 K, and a more brilliant blue, such as sky blue, when heated to a temperature of 60,000 K to 100,000 K. The characteristics of a blackbody at different temperatures are defined by Planck's law. (See page 1–8.) The locus of blackbody chromaticity on the diagram shown in Fig. 4–6 is known as the Planckian locus.

Any chromaticity represented by a point on this locus may be specified by color temperature. Color temperature should not be used to specify a chromaticity that does not lie on the Planckian locus. However, what is called the *nearest* or *correlated* color temperature is sometimes of interest, and has been defined.[18] The loci of *isotemperature lines* that may be used as an approximation to obtain a reading on the diagram of the *nearest* color temperature are shown in Fig. 4–7.

Equal *color differences* are more nearly expressed by equal steps of *reciprocal* color temperature than by equal steps of color temperature itself.

A difference of one microreciprocal degree $\left[\frac{1}{CT} \times 10^5 = 1 \text{ mired (pronounced mý-red)}\right]$, indicates approximately the same color difference anywhere on the color temperature scale above 1,800 K; whereas 1 mired is derived from a difference that varies in color temperature from about 4 degrees at 1,800 K, 25 degrees at 5,000 K, 46 degrees at 6,700 K, to 100 degrees at 10,000 K.

Color temperature is a specification of chromaticity only, and has nothing to do with the energy distribution of an illuminant. The chromaticities of many "daylight" lamps plot very close to the Planckian locus, as shown in Fig. 4–7. Their color may be specified in terms of *nearest color temperature.* However, this specification gives no information about their spectral energy distribution and must be used cautiously. (See Fig. 4–10.)

Correlation between Methods of Color Designation and Specification

The various forms of color designation and specification are frequently encountered under circumstances which require or make desirable the conversion of the notation or specification for a color from one system to another, just as dimensions in feet are often converted to dimensions in meters.[19]

I.C.I. co-ordinates to or from dominant wavelength and purity. Plot the spectrum locus on an $x - y$ diagram and plot the location of the illuminant as in Fig. 4–6. Draw straight lines from the illuminant point to the spectrum locus at regular intervals (0.001, 0.01, or 0.1 micron). All colors whose $x - y$ co-ordinates fall on one of these lines have the *dominant wavelength* indicated by the intersection of the line with the spectrum locus. Their *purity* is determined by dividing their distance from the illuminant point by the distance along the same line from the illuminant point to the spectum locus. One hundred per cent purity is at the spectrum locus; colors of 50 per cent purity fall halfway between the illuminant point and the spectrum locus, 0 per cent purity is at the illuminant. Reflectance equals the Y value of the I.C.I. co-ordinates, and may be obtained by heterochromatic photometry.

Any $(x - y)$ specification is accurate only for the illuminant for which it is calculated. The dominant wavelength and purity corresponding to any $x - y$ specification also depend on the illumination. For example, $x = 0.41$, $y = 0.40$ is a blue—dominant wavelength approximately 0.492 micron and purity 10 per cent when referred to illuminant A; but the same $(x - y)$ point when referred to illuminant C is a yellow—dominant wavelength 0.590 micron and purity 50 per cent.

I.C.I. co-ordinates to or from Munsell notation. A complete set of charts of the type shown in Fig. 4-8 has been prepared by a subcommittee of the Colorimetry Committee of the Optical Society of America. Instructions for converting from I.C.I. to Munsell notation and vice versa are included.[20]

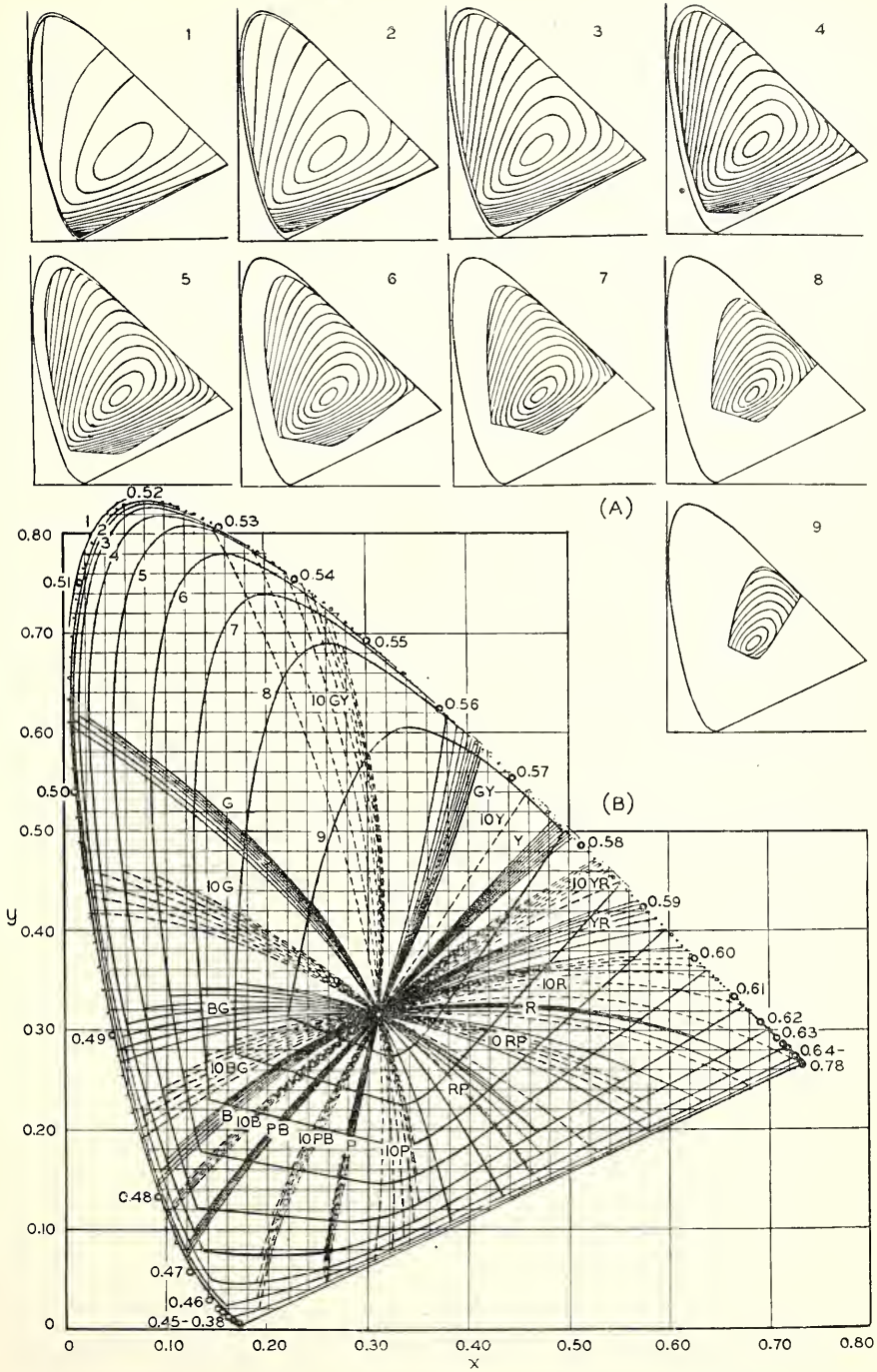


FIG. 4-8. Conversions between I.C.I., Munsell, and dominant wavelength notations may be made directly on charts such as these.[20] (*A*) Constant chroma loci for standard chromas at value levels 1 through 9. (*B*) Constant hue loci for standard hues at value levels 1 through 9.

I.C.I. co-ordinates from spectrophotometric curves. Although it is not possible to construct a spectrophotometric curve from a color specification in I.C.I. co-ordinates or other shorthand notation, I.C.I. co-ordinates x, y and Y may be obtained from spectrophotometric curves. The example given in the Appendix on page A–24 illustrates the procedure[21] for making the necessary computations for a deep red reflecting surface whose spectral reflectance curve is given in Fig. 4-9. Solutions by both the weighted ordinate and selected ordinate methods are explained and Appendix Table A-13 on page A–28 gives selected ordinates for illuminants A, B, and C. A mechanical integrator, by means of which much of the numerical work of the selected ordinate method may be eliminated, is a time-saving tool.

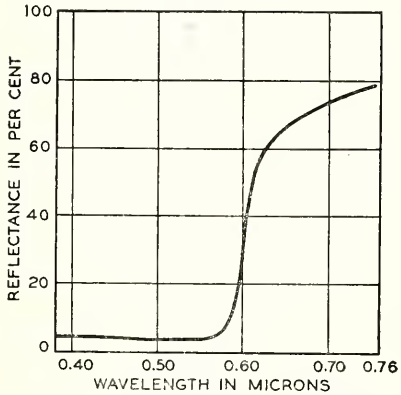


FIG. 4-9. Spectral reflectance curve for a vivid red surface Munsell R 4/14. 1 micron = 10,000 angstroms = 1/10,000 centimeter.

Color Harmony in Design

Many theories of color aesthetics have been published. Most of these are expressed in terms of one or another of the numerous systems of surface color designation. To a considerable extent, they represent codifications of artistic taste and experience. Although many of these differ greatly in many details, a few general principles have been expressed repeatedly.[14,15,22,23,24]

Both the purpose of a color scheme—whether in a factory or night club, on a machine or on a stage—and the amount, quality, and distribution of illumination that is to be available, should be known before colors are selected.

Composition and design are always of paramount importance. A good color combination will be most pleasing when used in a good design, and an excellent design can make almost any combination of colors acceptable. Consequently, it is possible to find or create exceptions to all "rules" of color harmony.

Consistency of both design and color can be maintained without monotony. It is possible to use a single hue exclusively if variations of value (luminous reflectance) and chroma are employed in a design that provides interest, accent, and variety. The use of one or more hues contrasting with the dominant hue is the most common method of avoiding monotony.

Contrasting hues of high chroma are most effective when used in small areas. Light colors (high reflectance) are effective as accents in dark surroundings (prevalently low reflectance), and dark colors are effective for variety and interest in light surroundings. Contrasting hues may be, but need not be, complementary.

Triads of hues, two of which are related but not too nearly alike and the third of which is approximately complementary to the average of the pair, are often effective. The pair may be used together to establish the dominant hue, or they may be used for accent and variety. It is usually best to treat the neighboring hues of a triad in a similar manner, assigning approximately equal areas to each and using equal ranges of value and chroma.

All principles, such as the preceeding examples, may be violated successfully by clever designers, but greater care and ingenuity are necessary in breaking the rules than in observing them.

Psychological and physiological sensations attributed to color. In almost every discussion of the aesthetic factor in color schemes some correlation between color and nonvisual sensations is suggested. The most popular association consistently emphasized by artists is the supposed relationship of the red colors (red purple, red, orange, and yellow) with warmth and the blue colors (bluish purple, blue, and blue-green) with lack of warmth. This appears to have no foundation in fact.[25]

Color Selection, Grading, Matching, Control, and Tolerances

No factor is more important in problems of color selection, matching, control, and grading than the spectral distribution (color) of the illumination on objects under observation.

Color selection. If the problem is one of simple selection, as for example that faced by the housewife about to choose from an assortment of meat, at the meat dealer's, or of fruit or vegetables at the grocer's, or from an assortment of dress and upholstery fabrics, paints, or wallpapers at a department store; the decision will be based on the appearance of the object on display and upon the customer's estimate of its probable appearance under the conditions most likely to be encountered in use. The conditions of display and use differ more often than they coincide. This is particularly true of the illumination.

If spectrophotometric facilities are not available, color matches satisfactory for many purposes may usually be assured by the simple expedient of checking the match under each of two illuminants of complementary color, red and green, for example, or yellow and blue. For many simple matching problems a low wattage incandescent lamp and a blue or daylight fluorescent lamp are adequate.

A perfect match under all conditions will be obtained by matching spectrophotometric curves of the type shown in Figs. 4–9 and 4–10. Two surfaces having identical curves are in general identical in color to each other under all conditions although if their surface textures are not the same (smooth paint and rough textiles, for example), their appearance may vary slightly depending on the angle from which they are illuminated and viewed.

Color grading and matching. The market value of many things—raw cotton, tobacco, fruit, vegetables, furs, textiles, and so forth—varies with their colors over a very wide range. In some instances such products are accepted or rejected on the basis of color specifications or standards. They

may be separated according to nearly imperceptible color differences into a number of "standard" grades each of which may have a different market value.

It is frequently necessary to obtain a "commercial match" between physical samples (supplied for purposes of specification) and production samples (selected for purposes of production quality control). The test procedures under the specifications should be so defined that experienced persons consistently and independently assign the same grades and make the same matches.

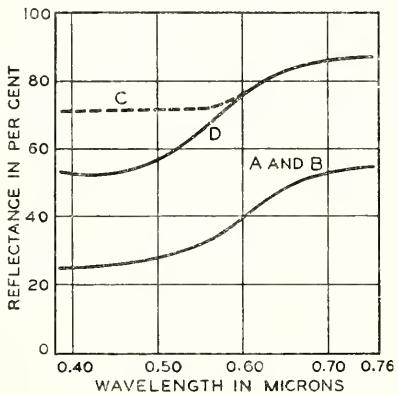


FIG. 4-10. Spectral reflectance and transmittance curves reveal slight differences between samples which may not be detected by visual observation under ordinary light sources. To a normal observer, samples *A* and *B* seem to match as do *C* and *D*, when viewed under incandescent lamps; *C* and *D* are pink but of higher value (luminous reflectance) than *A* and *B*. While the spectral reflectance curves prove the physical similarity of *A* and *B*, they reveal a difference between *C* and *D*. *A* and *B* will match under any conditions, but *C* and *D* will not match if the illumination contains a high percentage of blue energy in the region 0.4–0.5 micron.

Color control in a lighting installation. The artist, architect, and illuminating engineer, after agreeing on a design having suitable decorative qualities and which at the same time will provide the proper quantity and quality of illumination, have the problem of transferring their plans to the room in question. This must be done by specifying to the contractor and builder, as well as to the furniture, wall covering, drapery, and paint manufacturers, what materials will be acceptable from a color standpoint. The fundamental problem is similar to that worked out by the retail packaging experts.

Color control in production. There are many reasons for requiring accuracy and precision in the control of the color of surface coatings, such as printing inks and industrial finishes. Perhaps the most important reason concerns the demands made by the buyers of retail consumer goods, and the quality significance they attach to the color of articles.

The use of color control usually has three objectives. The first objective is that a satisfactory match for the desired color should be obtained with the type of coating formulation which will be used in production. The second objective is that the standard color achieved as a result of the first should be maintained during the first mass production of the material. The third objective requires that subsequent mass productions of the material have the same color as the first mass production. For those articles which are in almost continuous mass production, such as cigarette containers where the production for a single brand may be several million packages

a day, the last two are the same. An excellent description of the color control procedure applied in the packaging field was given by Granville in *Illuminating Engineering* in December, 1944.[25]

Spectrophotometric control. The type of color standardization and control provided by spectrophotometric measurements has increased in use. Such measurements provide a permanent record which can be converted into a color specification. The application of the spectrophotometer to the problem of color standardization for production control purposes is almost universally recognized as the best approach though not the only one.[21, 27]

Color tolerances. Tolerances are generally thought of in terms of color differences; however, color tolerances should be considered also on the basis of what can be done in production. One type of tolerance limit is caused by production difficulties. Once selected, tolerances can be specified spectrophotometrically, and tolerance limits can be prepared for visual comparison on a production basis.[28]

Illuminants for Color Work

Surface colors which match in one quality of illumination but do not match in another invariably result from unlike spectral reflectance curves. Conversely a spectral energy match is, in general, required of any illuminant intended as a substitute for another whenever colors are to be examined critically.

Any change in the characteristic spectral curve of illuminants used as substitutes for each other will cause differences in the appearance of objects seen under them. The amount of color constancy or color change will depend on the spectral distribution of the illuminant and on the spectral reflectance of the object. If the spectral reflectance of an object is nonselective, that is, equal in all parts of the spectrum (as for nonselective whites, blacks, and grays), then there will be little difference in appearance under two illuminants that have the same color temperature but do not have similar spectral energy distributions.

Artificial daylighting. Specifications for the best artificial daylighting for use in grading include: a large source of relatively low brightness; duplication of color of moderately overcast north sky; illumination of at least 75 footcandles for inspecting light colors, more for dark colors.

The color specification for an artificial daylight illuminant should be aimed at the best obtainable duplicate of preferred natural daylight conditions. Most commercial grading is done under natural daylight and for such grading the results of classification under artificial and natural daylighting should agree. Also, it takes years of experience to make a good classer, grader, or inspector, and an accurate memory of color standards is a necessity. Any great change in illumination requires that classers make adjustments in their memory of standards. The greater the change, the more difficult this becomes. If artificial illuminants are to be preferred rather than be merely tolerated for color grading, psychological as well as physical standards must be maintained.

Inspection for suitability of color of materials to be used in daylight (as by a customer in a retail store) requires only an approximate duplication of the spectral-energy distribution of natural daylight, because large object-color variations are tolerable. The normal eye adapts readily to rather large changes in the chromaticity of an illuminant so that the apparent colors of objects remain approximately constant.

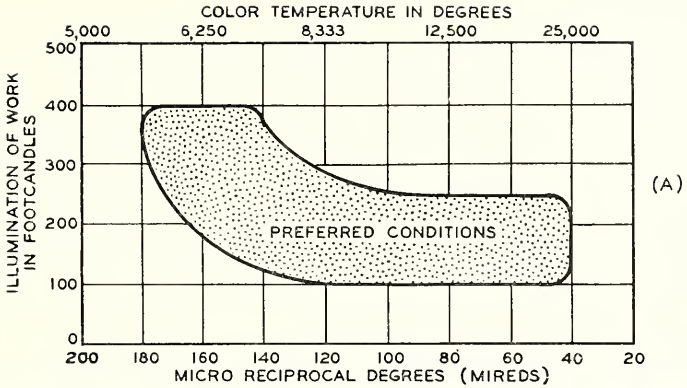
Color grading of a group of material samples known to have similar spectral-reflectance characteristics may require close duplication of the spectral-energy distribution of daylight. This use, however, differs from the other uses listed because large departures from the spectral-energy distribution of natural daylight are allowable as long as they yield in undiminished amount the object-color differences characteristic of daylight inspection. Whenever, as is frequently true, the artificial illuminant magnifies the characteristic differences so that they may more easily be detected, departures from the spectral-energy distribution of natural daylight are desirable. If yellow samples are to be examined, an illuminant rich in energy in the blue portion of the spectrum, where the spectral reflectances of yellow samples are apt to differ most widely, will enable an observer to discriminate differences more easily than when using an illuminant deficient in the blue portion of the spectrum. When blue samples are to be examined, the reverse is true; i.e., an illuminant rich in energy in the yellow portion of the spectrum will facilitate discrimination. It should be remembered that while differences may be revealed by such a method the average daylight appearance of the samples will not necessarily be revealed. If the observer is an experienced color-grader, duplication of the natural daylight chromaticity familiar to him will permit him to take full advantage of his previous experience and will make conversion to the new conditions much less difficult.[29]

A practical application of this general method is used in dye houses. When samples are to be matched they are viewed under two illuminants selected at or near the extremes of daylight color temperatures.

Preference of textile color matchers. Data obtained by an Inter-Society Color Council Committee indicates that the footcandle and color temperature combinations of natural daylight preferred by textile color matchers are as shown in Fig. 4-11A. At 100 footcandles, the minimum color temperature preferred is close to 7,500 degrees, and the maximum is above 25,000 degrees. The preferred color temperature may drop to 5,700 degrees for values of 300 or more footcandles.[31]

Skylight design for natural daylight. The government-type skylight (Fig. 4-11B) used in many commercial and government cotton-classing rooms was developed for the United States Department of Agriculture.[30] The glass faces due north and its departure from the vertical changes with the latitude to exclude direct sunlight. The length varies from 30 to 90 feet, the longest skylight being the most satisfactory.

While such natural daylighting of color grading rooms has been successful, many rooms cannot be placed on a top floor, or be so oriented that a long north skylight is possible. Even when light from a north window has been used satisfactorily for years, taller buildings built near by may shut



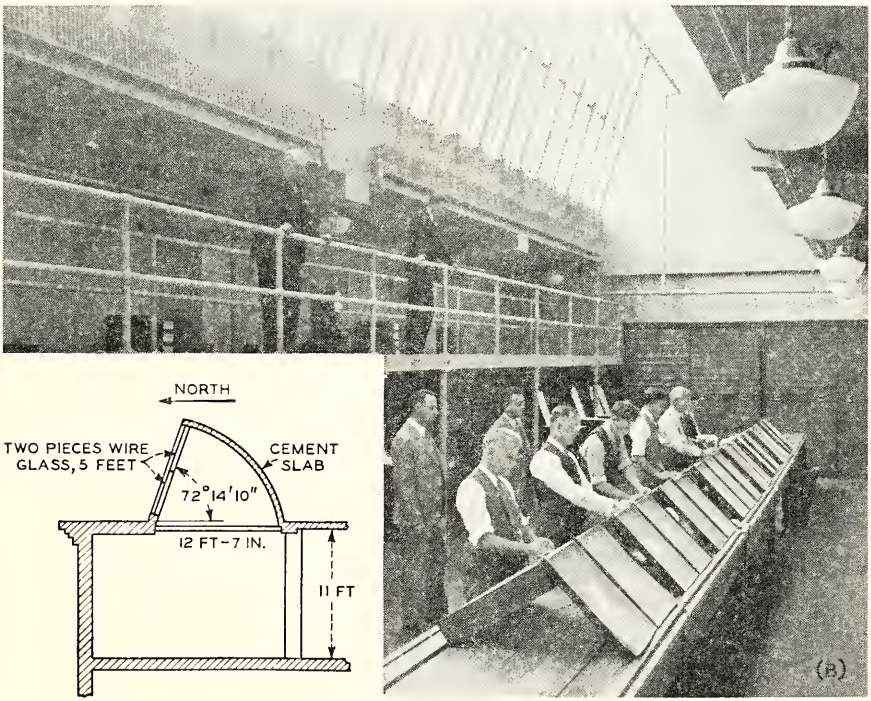


FIG. 4-11*A*. Tests conducted under the direction of the Intersociety Color Council show the characteristics of preferred daylight illumination conditions for color matching, grading, and classing. *B*. Government type skylight; glass faces due north running east and west; all reflecting surfaces are finished in neutral white or gray.

off the light or change its color by reflection from colored walls. The weather may be bad during the peak of a classing season, and extra work may pile up that cannot be completed within the few hours of good light available each day.

Artificial skylight for preferred daylight color rendition. The lamp-and-filter unit shown in Fig. 4-12 approximates 7,500 degrees Kelvin color temperature and has a spectral distribution similar to daylight of that color temperature. It was developed for cotton classification. On a run of over 2,000 test classifications it was found that a somewhat greater consistency of classification was attained under the uniform quantity and quality of illumination provided by this artificial source than under natural daylight, and no significant differences in classification have been noted. Cotton classing groups which now use this unit are satisfied with the results obtained as are many other grading and inspecting groups which have adopted it for their work.



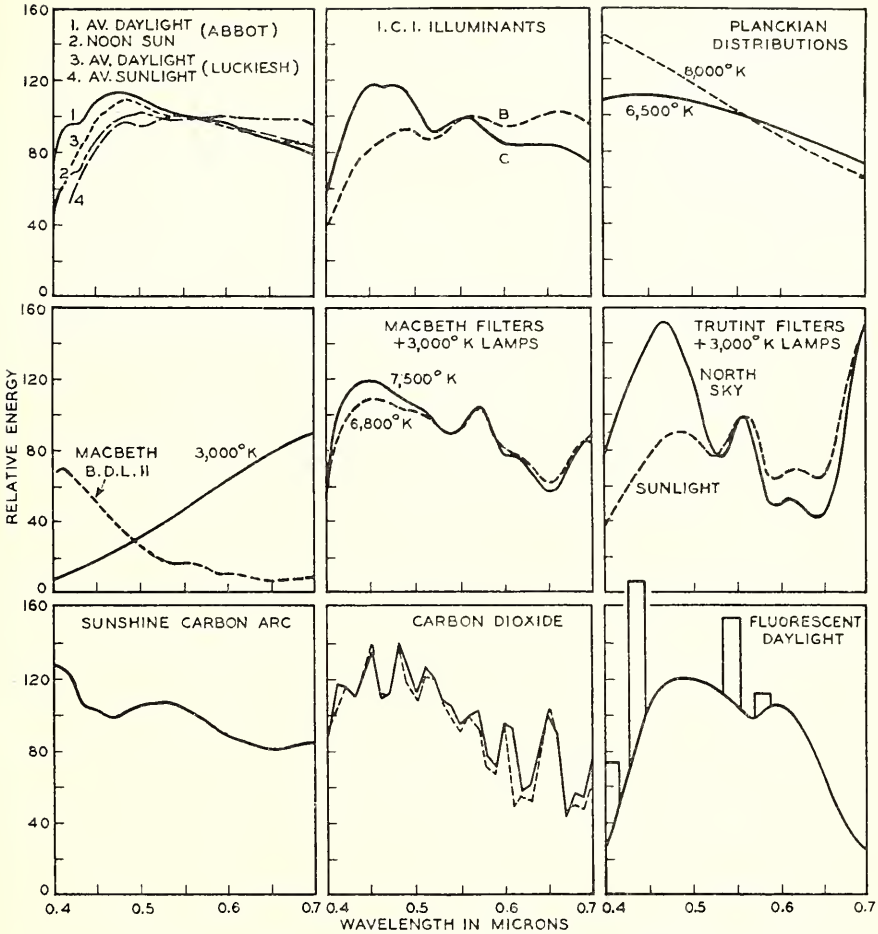
FIG. 4-12. Artificial skylight used at the Division of Cotton Marketing, U. S. Department of Agriculture, for color grading of agricultural products. Fifteen lamps and filters are mounted behind a diffusing glass panel in a ventilated enclosure finished with heat absorbing white paint.

A similar type of unit approximating I.C.I. illuminant C in color temperature and several other "daylight" sources such as the high-temperature carbon arc, carbon dioxide and fluorescent tubes, and so forth were considered before the 7,500-degree color temperature was recommended, but they were found less satisfactory.[30]

Figure 4-13 includes curves of relative spectral energy distribution for a number of actual and theoretical illuminants that have been considered as daylight substitutes.

Imperceptible supplementation of natural daylight requires careful duplication of the particular phase of natural daylight supplemented. *Color matching* of materials to be used in daylight (in dyeing textiles, and so on); *color inspection* of materials to be used in daylight for conformity, within a specified tolerance, to a given color standard; and *photographic sensitometry* all require close duplication of the spectral-energy distribution of natural daylight in the illumination specified for the work.

Color photography is in all essential respects analogous to color vision. Illuminants intended as substitutes for, or to supplement daylight for color photography should have very nearly the same spectral distribution as the illuminant replaced. Neither color temperature nor a visual color match is a sufficient specification for illuminants used in color photography.[32] (See Section 14.)



1 micron = 10,000 angstroms = 1/10,000 centimeter

FIG. 4-13. Spectral energy distribution curves for illuminants sometimes considered as substitutes for natural daylight.

Paint mixing. When a painted surface of a certain color is desired, it is often possible to select satisfactory colors from the stock samples found on manufacturers' color cards. However, if the manufacturers' stocks do not include the desired color, and the painter wishes to mix his colors, mixing guides are available which suggest the proportion of various raw ingredients for each of the paint chips included. (See page 4–6.)

To be sure of an exact match with the sample selected, it is necessary to use the specific raw materials and proportions recommended and to check the match using the illumination under which it will be observed. In mixing small quantities (a pint or less) it is sometimes difficult to measure accurately the relatively minute quantities of certain raw materials required and for this and other reasons it is often difficult to make a close match. This is particularly true of high value, low chroma (pastel) colors.[33]

Spectrophotometry

Spectrophotometry is the measurement of spectral reflectance and transmittance.[21] Colorimetric data may be obtained from spectrophotometric measurements which have been converted to I.C.I. notation. (See page 4–16.)

The *modes of illumination and collection* differ in various spectrophotometers. Since the results depend on the slit width, the illumination and collection geometry, and the calibration, these should be reported clearly with each spectrophotometric curve.

Gloss has a marked effect on the object color perceived but gloss itself is best measured with instruments such as a goniophotometer. (See Section 5.) The color corresponding to any particular mode of illumination and observation can, in principle, be determined from separate and independent determinations of the color and gloss of any sample.

In a spectrophotometer a spectroscope disperses the light into its components and a photometer measures the amount of light of each wavelength transmitted or reflected by a sample, by comparing the unknown quantity with a standard. In early models, the judgment of match was made by eye. This was time-consuming, even if measurements were made only at 0.02- or 0.04-micron wavelength intervals. Also, if a tungsten filament lamp is used as the light source in a visual instrument, it provides so little light in the blue end of the spectrum that it is very difficult to make either precise or accurate judgments.

However, photoelectric spectrophotometers are not as greatly handicapped in this way and several are now available in which the illumination is satisfactorily provided by a tungsten lamp chosen because it is convenient and emits a continuous spectrum. The latter is a usual requirement in spectrophotometry for if the illumination falling on a sample surface has no energy in some part of its spectrum, then no energy can be reflected or transmitted for measurement in that part of the spectrum, no matter how much a sample may be able to reflect or transmit in that region.

Present commercial models of the best-known automatic recording instrument, shown in Fig. 4-14A, illuminate the sample about 6 degrees from the normal, and view it diffusely by gathering light from the white interior surface of a hollow sphere. The results correspond to the appearance of the sample when held perpendicular to the line of sight in completely diffused indirect lighting.[34, 36] A manual type of instrument is shown in Fig. 4-14B.[35, 36]

The optics of any spectrophotometer must be designed to utilize as much as possible of the available energy so that narrow slit widths may be used in making measurements. A good spectrophotometer source must emit enough energy in all portions of the spectrum so that measurements may be made with slit widths that admit light from bands 0.01 micron or less in width.

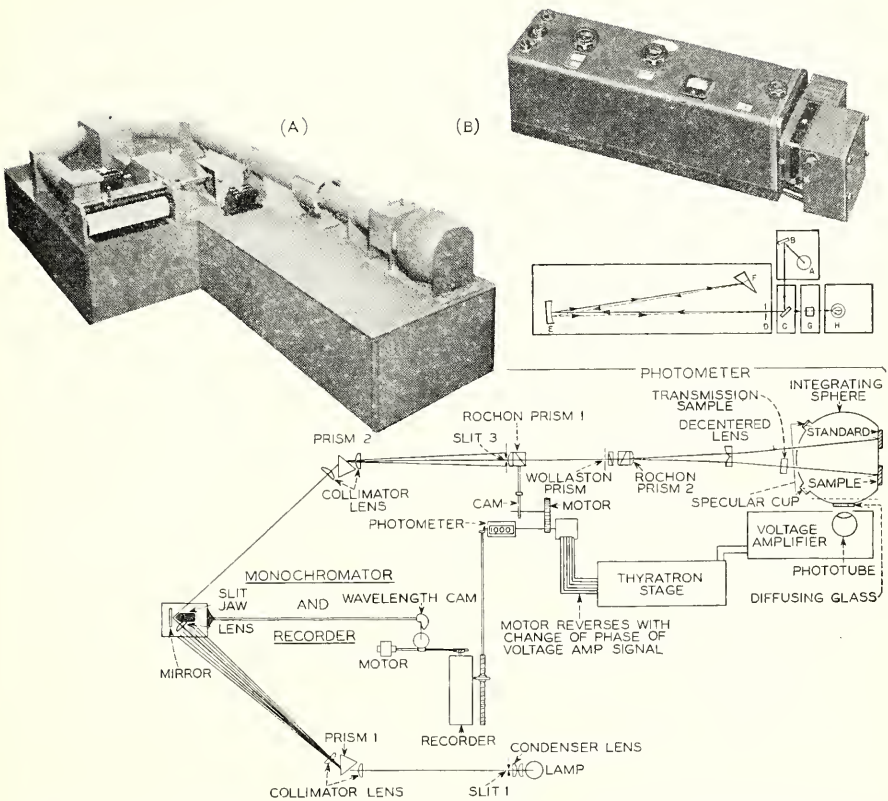
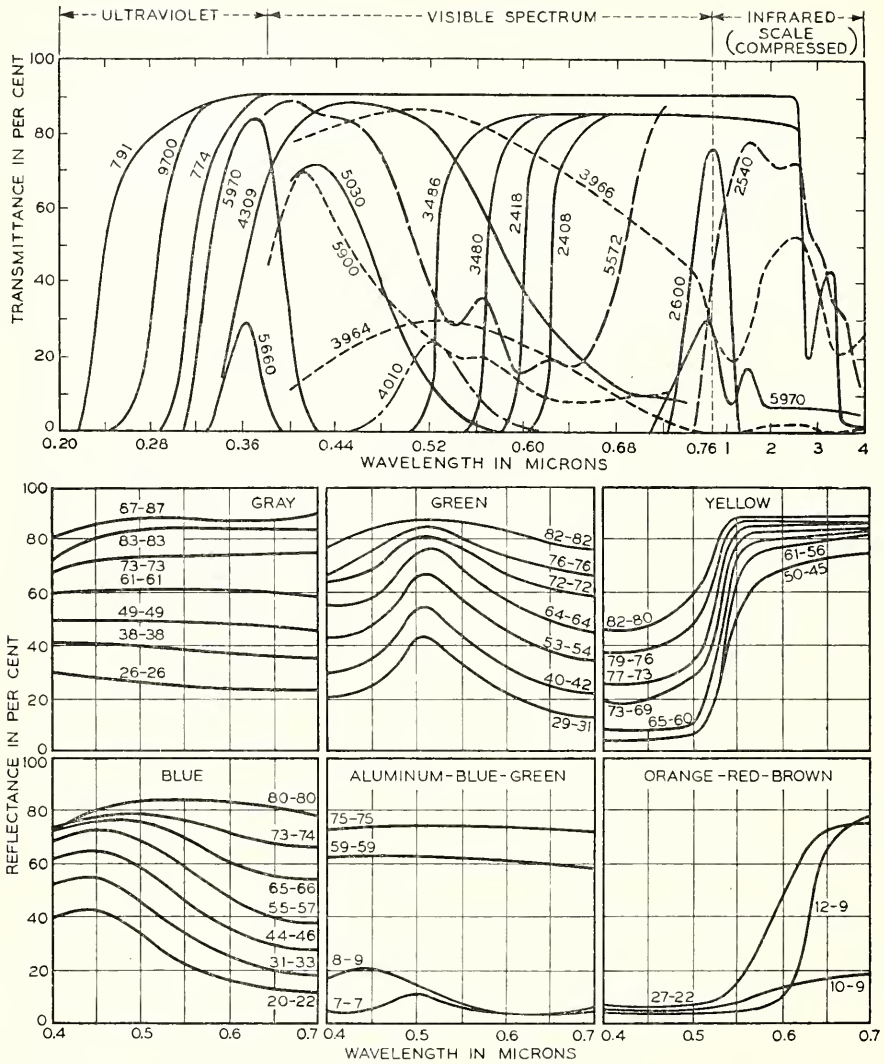


FIG. 4-14. Typical photoelectric spectrophotometers, (A) automatic recording type, (B) manual type.

Incidence at substantially 45 degrees from the normal to the surface and collection or observation of the light reflected perpendicular to the surface were the conditions recommended by the I.C.I. in 1931, and these conditions are realized approximately in some instruments. However, this condition was omitted from ASA Z44-1942 (page 32), since agreement on the best viewing and illuminating geometry had not been reached. Illumination substantially perpendicular to the surface and collection of substantially all the reflected energy represent the condition most commonly used because of its efficiency in photoelectric instruments and because objects made with the same colorants but having markedly different surface characteristics (e.g., dull and glossy) give nearly the same results under this condition. In this manner, the color measurement can be made nearly independent of gloss.

Spectrophotometric measurements on a sample—provided there is enough light to make precise measurements, and provided wavelength bands are equally narrow—will be the same regardless of the illuminant as



1 micron = 10,000 angstroms = 1/10,000 centimeter

FIG. 4-15. Spectral transmittance curves for a number of ground and polished samples of various melts* of glass (top). (below) Spectral reflectance curves for various painted surfaces. The luminous reflectance in per cent for incandescent lamps is indicated by the left hand figures. The right hand figures indicate luminous reflectance for daylight fluorescent lamps.

long as the illuminant used emits energy of all wavelengths. A color-blind observer using the direct visual comparison type of spectrophotometer may make measurements quite as accurately as an observer with normal color vision, since all that is necessary is an accurate judgement of brightness equality.

An automatic recording spectrophotometer may produce a continuous

* Figures on curves refer to standard melts of the Corning Glass Works. Transmittance decreases rapidly as the sample thickness increases and vice versa.

curve or a table of transmittance values at specified wavelength intervals (usually 0.02 micron).

Figure 4-15 shows spectral reflectance and transmittance curves obtained with a spectrophotometer for a number of different samples of common materials.

Colorimetry

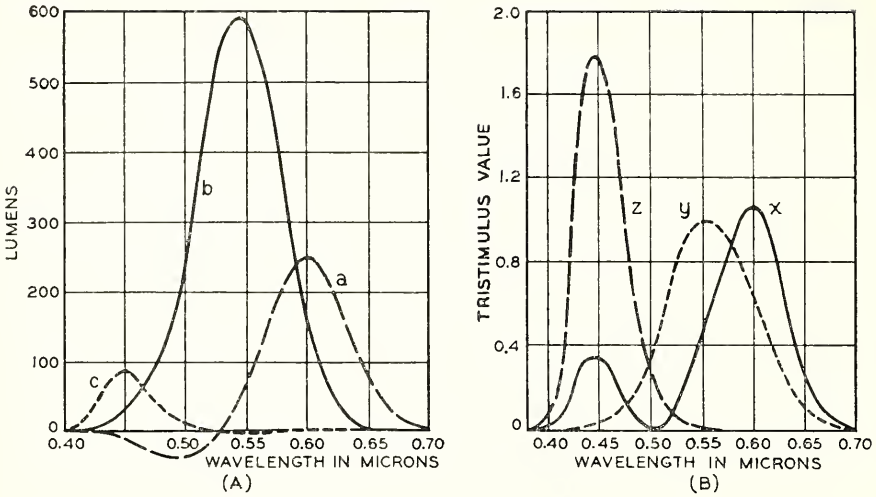
Color and the color properties of objects may be measured in many ways, all of which involve, either directly or indirectly, visual comparisons of a sample with optical combinations of measured quantities of several (usually three) fixed or physically specifiable qualities of light.[37]

Direct colorimetry is simpler than indirect but is subject to errors and uncertainties arising from the nonuniform spectral sensitivity of any observer and individual differences of considerable and variable magnitude between observers. In some applications, such as product inspection and quality control, direct visual comparison is preferable because of the flexibility and simplicity of the procedure.

Indirect colorimetry utilizes spectral distribution data for sources, spectrophotometric data for surfaces, and standard colorimetric data representative of a normal observer. Standards and tolerances for inspection and control are best established and maintained by spectrophotometry and indirect color measurement. Only by this method can long-term changes resulting from fading, drift, loss, or destruction of the standard, be avoided.

Color mixture. Both direct and indirect methods of color measurement are based on the fact that a color match can be established between optical mixtures of any sample color and variable amounts of three standard colors. In some cases, one of the standard components must be combined optically with the sample light in order to match some combination of the other two standards and the amount of the standard mixed with the sample is then recorded as a negative quantity. In rare instances, two of the standards need to be mixed optically with the sample light in order to match the third standard and the amounts of the two standards mixed with the sample are both recorded as negative quantities. Curve *a* in Fig. 4-16*A* shows the number of lumens (spectrally pure red primary, wavelength 0.65 micron) required to establish a match with one watt of spectrally pure energy at each indicated wavelength, when two other spectrally pure components, wavelengths 0.538 micron and 0.425 micron, are used (in the proportions indicated in curves *b* and *c*) as the other primaries. Curve *b* in Fig. 4-16*A* indicates the number of lumens of the yellowish green primary (0.538 micron) required for these color matches. Curve *c* in Fig. 4-16*A* indicates the required number of lumens of the bluish purple primary (0.425 micron).

Photoelectric colorimeters are frequently described, but since no photoelectric cells, nor any photocell-filter combinations, have yet been developed with the color response of the human eye, none are entirely satisfactory. A few have been built that approach the desired accuracy including the instruments built and used by Barnes,[38] and the Hunter instrument[39] widely used in the paint industry.



1 micron = 10,000 angstroms = 1/10,000 centimeter

FIG. 4-16*A*. (*a*) Lumens of 0.65 micron red component in mixture with 0.538 micron (yellowish green), and 0.425 micron (bluish purple), which matches color of one watt of energy at each spectrum wavelength; (*b*) lumens of 0.538 micron (yellowish green); (*c*) lumens of 0.425 micron (bluish purple). *B*. Standard I.C.I. color mixture data obtained by linear combination of *a*, *b*, and *c*. *Y* is identical to the standard relative luminosity curve.

Empirical colorimeters employing the subtractive principle have been built for specific purposes: the Lovibond tintometer for use with Lovibond glasses, another designed by Judd for very precise measurement of small chromaticity differences,[37] and the Eastman color densitometer. There are others of the additive type, such as the disk colorimeter originally designed for use in the grading of agricultural products.[27]

Three-color colorimeters, which use spectrum components, have been described by Wright in reports of many research problems.[37] Other three-color colorimeters using filters, such as those designed by Guild and Donaldson, are used in England. Instruments have been described and built for the direct determination of dominant wavelength, but little or no commercial application has been made of this type.

Color comparators. Two classes of instruments commonly called colorimeters should be distinguished. The first is that just described. The other is employed principally in chemical analysis for determining concentrations of solutions, or for the empirical grading of samples according to color. These might better be called color comparators as they are not true measuring instruments.

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SECTION 5

THE MEASUREMENT OF LIGHT

The fact is well established that progress in a branch of science or engineering is expedited materially by each advance in measuring technique and by each improvement in measuring apparatus.

The measurement of light is called photometry and devices used for this purpose are usually called photometers.

For many years photometric measurements depended on visual observations. The characteristics of the human eye vary widely in groups of observers, and over a period of time even in one observer in an unpredictable manner. Because of these variations the accuracy and precision practically attainable with visual photometers is limited.

Although physical photometers, utilizing photoelectric cells, thermopiles, or bolometers, are not subject to the errors introduced by the variable characteristics of the human eye, frequent calibration is necessary if the maximum practicable accuracy and precision of which they are capable is desired.

The response characteristics of many photosensitive elements vary between individual samples of the same type and manufacture, are not constant with time, and, except when compensated (with a special filter, for example), are not similar in spectral response characteristics to the standard (I.C.I.) observer. (See Fig. 1-2, page 1-5.) When the spectral distribution (color) of the light measured is not the same in every case as the standard used in calibrating the instrument (the colors of natural daylight, incandescent, fluorescent, mercury and sodium lamps are different) this deviation from I.C.I. response characteristics may introduce very large errors. The most common types of light meters which employ barrier-layer cells are also subject to errors introduced by a variation in the angle of incidence of the light being measured. Thus it is evident that the measurement of light is a painstaking task requiring skill, care, and common sense as well as good equipment.

Measurable Characteristics

As indicated in Table 5-1, many characteristics of light, light sources, lighting materials, and lighting installations may be measured. The measurements of most general interest are:

1. Illumination.
2. Brightness.
3. Intensity in a specific direction, and intensity distribution.
4. Luminous flux.
5. Color temperature.
6. Spectral distribution.

Basic Photometric Principles

Almost every photometric measurement involves a consideration of the

NOTE: References are listed at the end of each section.

Table 5-1. Some Measurable Characteristics of Light, Light Sources, and Lighting Materials

CHARACTERISTIC	DIMENSIONAL UNIT	EQUIPMENT	TECHNIQUE
		LIGHT	
Wavelength	micron	Interference grating	Laboratory
Color temperature	degree	Pyrometer	Laboratory
Flux density	lumens/sq ft	Photometer	Laboratory or field
Orientation of polarization	degree (angle)	Analyzing Nicol prism	Laboratory
Degree of polarization	per cent	Polarization photometer	Laboratory
		LIGHT SOURCES	
Energy radiated	ergs/sq in.	Calibrated radiometer	Laboratory
Luminous intensity	candle	Photometer	Laboratory or field
Brightness	footlambert	Photometer or brightness meter	Laboratory or field
Spectral energy distribution	ergs/micron	Spectrometer	Laboratory
Power consumption	watt	Wattmeter, or (for dc and 100 per cent power factor a-c circuit) voltmeter and ammeter	Laboratory or field
Light output (total flux)	lumen	Integrating sphere photometer	Laboratory
		LIGHTING MATERIALS	
Reflectance	per cent (dimensionless ratio)	Reflectometer	Laboratory or field
Transmittance	per cent (dimensionless ratio)	Photometer	Laboratory or field
Spectral reflectance and transmittance	per cent (at specific wavelengths)	Spectrophotometer	Laboratory
Optical density	dimensionless number	Densitometer	Laboratory

inverse-square law (which is strictly applicable only for point sources) and the cosine law.

The *inverse-square law* (see Fig. 5-1) states that the illumination E of a surface varies directly with the candlepower I of the source and inversely as the square of the perpendicular distance d between the source and the surface:

$$E = \frac{I}{d^2}$$

This holds true only when the maximum dimension of the source (or luminaire) as viewed from the surface, is small (subtending less than

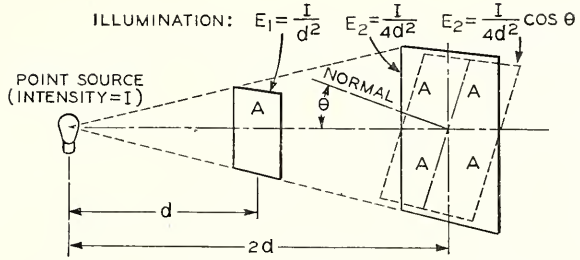


FIG. 5-1. The inverse-square law describes the geometrical relationship between a source and a surface illuminated by light from that source. Surfaces A and AAAA are portions of spheres with centers at the light source.

one fifth the distance between source and surface) and when the surface approximates a portion of a sphere of radius d with its center at the source.

The *cosine law* states that the illumination of any surface varies as the cosine of the angle of incidence θ (between the normal to the surface and the direction of the incident light):

$$E = \frac{I}{d^2} \cos \theta$$

The *cosine-cubed law* or *combined law* is a convenient derivation which is useful in many situations encountered in practice. The illumination of any element of surface is equal to the sum of the individual components of illumination produced by each contributing source. The individual components of illumination E_θ vary as the intensity I_θ of the source in the direction of the element and the cube of the cosine of the angle of incidence θ, and inversely as the square of the perpendicular distance h of the source above the element. For a number of point sources of which the location and candlepower in the direction of the element are known, this law may be expressed:

$$E = \Sigma\, I_\theta \cos^3\theta/h^2$$

Values of the trigonometric functions may be obtained from Appendix Table A-25, page A-39. For surface sources the function must be integrated for values of θ included between the bounding angles of the source. (See page 8-46.)

Comparison with a standard source. In theory, each photometric measurement is made by direct visual comparison with light sources which have been established by international agreement as standards of candlepower. (See page 3-2.) In practice, however, the comparison is indirect. The laboratory reference standard lamp is used instead of one or more basic standards such as the national standard carbon lamps. (See figure 3-1.) Since an observer cannot measure or judge visually with any degree of accuracy the intensity or lumen output of a source,

or the illumination or brightness of a surface, but can detect a very small difference in brightness between two surfaces, visual photometers usually provide for the convenient and simultaneous visual comparison of two immediately adjacent fields, one illuminated by the test source and one by a laboratory source of which the characteristics are known. By various means, the brightness of one or both fields may be adjusted until the two appear equally bright. The intensity of the test source may then be determined by means of the instrument calibration or by application of the inverse-square and cosine laws.

Physical photometers of which the spectral response approximates that of the I.C.I. observer eliminate the necessity for visual observation.

Field Measurements

It is often desirable and necessary to make photometric measurements outside the laboratory, and portable instruments have been developed for this purpose. Typical problems include interior and exterior lighting surveys of which a common objective is the compilation of reliable data on a new installation sufficient to determine compliance with specifications or recommended practice. Analysis of such data on an old installation may reveal the need for maintenance, modification, or replacement.

Since the method used may exert a great influence on the results of photometric measurements (particularly of those made in the field) the necessity of adhering to standardized procedures of measurement and interpretation is generally recognized. Such procedures have been developed by the Illuminating Engineering Society for obtaining the illumination in typical interior areas and the general principles set forth in these may be applied to the solution of other field survey problems. However, for equivalent accuracy, larger numbers of readings will probably be required in other cases since the procedures outlined on page 5-6 are the only standardized, short-cut, field methods available and were developed for specific application only under the described conditions.

The National Electrical Manufacturer's Association has developed a survey procedure for floodlighting installations which has been accepted by its members. A condensation is reproduced beginning on page 5-8.

Isolux diagrams such as those shown in Figures 8–20 and 8–21 on page 8–49 in most cases are obtained by taking readings at equally spaced intervals in representative areas, as, for example, along the straightaway, at intersections, and at curves. It has been proposed that street and highway lighting surveys may be made also through the analysis of carefully prepared photographs.[1]

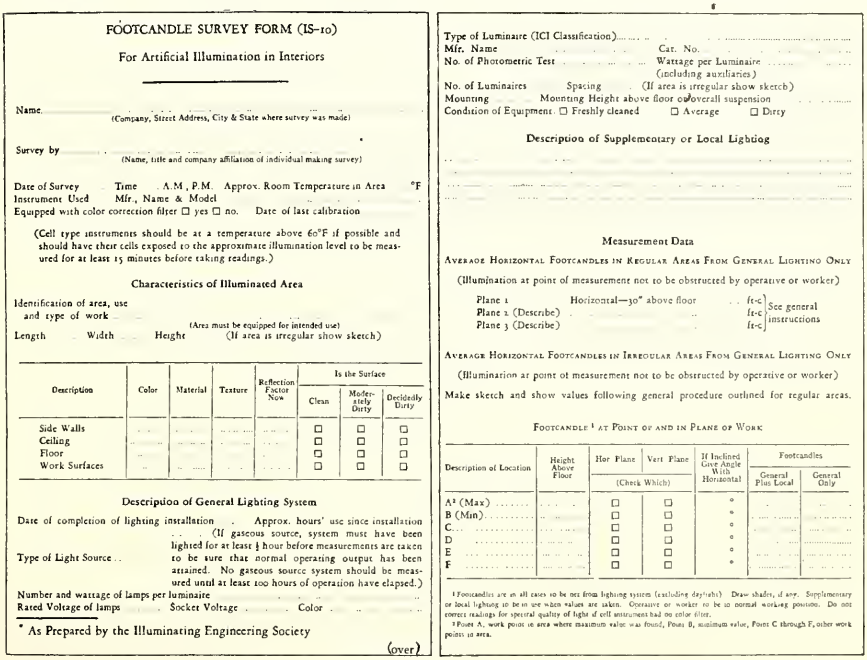
The probability of error when making footcandle measurements in the field is relatively high. Accuracies must not be expected that are beyond the limitations of the instruments used. Since illumination measurements apply only to the actual conditions existing during the survey (voltage, hours of burning, depreciation, and so forth), it is extremely important to record a detailed description of the illuminated area and existing conditions in the survey report.

Interior Lighting Survey Procedure

Light source seasoning period. No readings should be reported for discharge-source systems unless they have been operated for a total of at least 100 hours. The fluorescent type, particularly, requires not less than 100 hours of operation before stabilization of the light output can be expected. The published average depreciation during this period is approximately 10 per cent but field experience indicates that it may be higher in individual cases. With incandescent lamps, seasoning is accomplished by six hours operation at labeled volts.

Warm-up period. No readings should be taken of a discharge-source system until it has been in continuous operation at least half an hour. The light output of discharge sources, particularly fluorescent lamps, varies with ambient temperature, decreasing appreciably from rated values if the temperature adjacent to the lamp rises above or falls below the design ambient. The upper limits are often exceeded in poorly ventilated luminaires and a decrease in light output during the first half hour of operation results.

Standard record form. The official I.E.S. footcandle survey form, IS-10 (see Fig. 5-2), which may be ordered from stock at I.E.S. headquarters (51 Madison Avenue, New York 10, New York) should be used for recording survey data. Each form is accompanied by supplementary sheets rom which the following measurement procedures were condensed.[2]



FOOTCANDLE SURVEY FORM (IS-10)

For Artificial Illumination in Interiors

Name _____
(Company, Street Address, City & State where survey was made)

Survey by _____
(Name, title and company affiliation of individual making survey)

Date of Survey _____ Time _____ A.M., P.M. Approx. Room Temperature in Area _____ °F
Instrument Used Mfr., Name & Model _____
Equipped with color correction filter ☐ yes ☐ no. Date of last calibration _____

(Cell type instruments should be at a temperature above 60°F if possible and should have their cells exposed to the approximate illumination level to be measured for at least 15 minutes before taking readings.)

Characteristics of Illuminated Area

Identification of area, use and type of work _____
(Area must be equipped for intended use)
Length _____ Width _____ Height _____ (If area is irregular show sketch)

Description	Color	Material	Texture	Reflection Factor Now	Is the Surface: Clean	Moderately Dirty	Decidedly Dirty
Side Walls					☐	☐	☐
Ceiling					☐	☐	☐
Floor					☐	☐	☐
Work Surfaces					☐	☐	☐

Description of General Lighting System

Date of completion of lighting installation _____ Approx. hours' use since installation _____ (If gaseous source, system must have been lighted for at least ½ hour before measurements are taken to be sure that normal operating output has been attained. No gaseous source system should be measured until at least 100 hours of operation have elapsed.)
Type of Light Source _____
Number and wattage of lamps per luminaire _____
Rated Voltage of lamps _____ Socket Voltage _____ Color _____

* As Prepared by the Illuminating Engineering Society

(over)

Type of Luminaire (ICI Classification) _____
Mfr. Name _____ Cat. No. _____
No. of Photometric Test _____ Wattage per Luminaire _____ (including auxiliaries)
No. of Luminaires _____ Spacing _____ (If area is irregular show sketch)
Mounting _____ Mounting Height above floor or overall suspension _____
Condition of Equipment ☐ Freshly cleaned ☐ Average ☐ Dirty

Description of Supplementary or Local Lighting

Measurement Data

Average Horizontal Footcandles in Regular Areas From General Lighting Only

(Illumination at point of measurement not to be obstructed by operative or worker)

Plane 1 Horizontal—30" above floor _____ ft-c
Plane 2 (Describe) _____ ft-c } See general
Plane 3 (Describe) _____ ft-c } instructions

Average Horizontal Footcandles in Irregular Areas From General Lighting Only

(Illumination at point of measurement not to be obstructed by operative or worker)

Make sketch and show values following general procedure outlined for regular areas.

Footcandle [1] at Point of and in Plane of Work

Description of Location	Height Above Floor	Hor. Plane (Check Which)	Vert. Plane (Check Which)	If Inclined Give Angle With Horizontal	Footcandles: General Plus Local	Footcandles: General Only
A [3] (Max)		☐	☐	°		
B (Min)		☐	☐	°		
C		☐	☐	°		
D		☐	☐	°		
E		☐	☐	°		
F		☐	☐	°		

[1] Footcandles are in all cases to be net from lighting system (excluding daylight). Draw shades, if any. Supplementary or local lighting to be on use when values are taken. Operative or worker to be in normal working position. Do not correct readings for spectral quality of light if cell instrument had no color filter.
[3] Point A, work point or area where maximum value was found, Point B, minimum value, Point C through F, other work points in area.

FIG. 5-2. Standard I.E.S. interior lighting survey report form IS-10 (reduced).

PROCEDURES FOR DETERMINING AVERAGE HORIZONTAL FOOTCANDLES IN REGULAR AREAS

The flux of light method is employed to obtain the value of average footcandles. This is the quotient of total lumens on the working plane (30 inches above the floor) by the area in square feet.

The use of these procedures in the types of areas described should result in a value of average illumination within 10 per cent of the value that would be obtained by dividing the area into 2 foot squares, taking a reading in each square, and averaging. Except for the most exact specification, therefore, the saving in time to be made by using the suggested methods would justify this 10 per cent error.

Regular area with symmetrically spaced individual luminaires in two or more rows. (1) Select an inner bay of four units as shown in Fig. 5-3a. Take four readings (r, r, r, r). Repeat in a centrally-located bay and average the eight readings. (2) Select a half bay at each side of the room. Take two readings (q, q) in each midway between line of outside units and the wall, and average the four readings. (3) Select a half bay at each end of the room. Take two readings (t, t) in each midway between line of end units and the wall, and average the four readings. (4) In one corner of the room take one reading (p) as shown. Repeat in another corner and average the two readings.

$$\text{Average illumination} = \frac{A \times (B-1) \times (C-1) + D \times (B-1) + E \times (C-1) + F}{\text{number of luminaires}}$$

where
A = ft-c (step 1)
B = number of luminaires per row
C = number of rows
D = ft-c (step 2)
E = ft-c (step 3)
F = ft-c (step 4)

Regular area with single row of individual luminaires. (1) Select two half bays on each side of the room and take two readings (q, q) in each, as in step 2 above. Average the eight readings. (2) In one corner of the room take one reading (p), as in step 4 above. Repeat in another corner and average the two readings.

$$\text{Average illumination} = \frac{\text{(ft-c, step 1)} \times \text{(number of luminaires minus 1) (ft-c, step 2)}}{\text{number of luminaires}}$$

Regular area with single luminaire. (1) In each quadrant of the room take one reading (p), as in step 4 above. Average the four readings:

$$\text{average illumination} = \frac{\Sigma \text{ft-c}}{4}$$

Regular area with two or more continuous rows of luminaires. (1) Take four readings (r, r, r, r) near center of room as shown in Fig. 5-3*b* and average the four readings. (2) At each midside of room take one reading (q) midway between the outside row of units and the wall as shown.

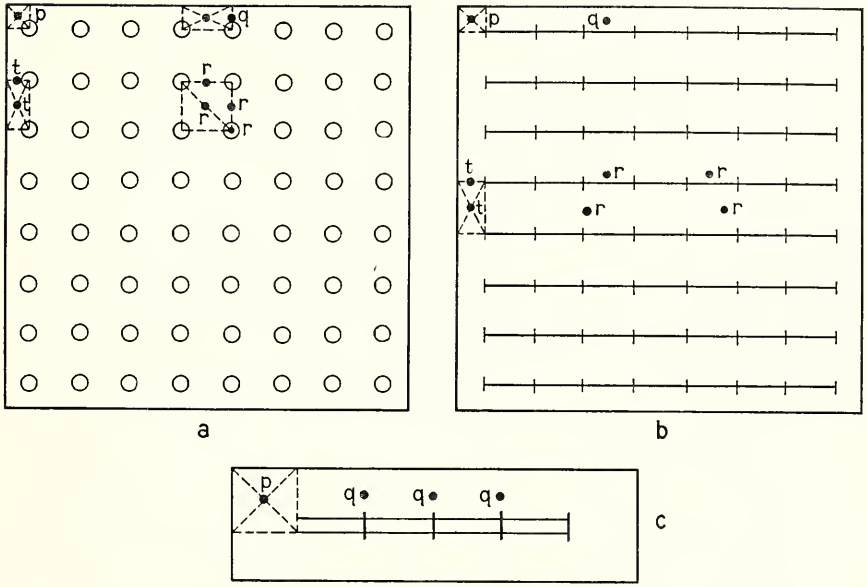


FIG. 5-3*a*. Location of illumination measurement stations in regular area with symmetrically spaced individual luminaires in two or more rows. *b*. Location of illumination measurement stations in regular area with two or more continuous rows of luminaires. *c*. Location of illumination measurement stations in regular area with one continuous row of luminaires.

Average the two readings. (3) At each end of room take two readings (t, t) one at end of a row midway between end of row and the wall, the other between rows and midway to wall as shown. Average the four readings. (4) In one corner take one reading (p) as shown. Repeat in another corner and average the two readings.

$$\text{Average illumination} = \frac{A \times B \times (C - 1) + D \times B + E \times (C - 1) + F}{\text{C} \qquad \times \qquad \text{B}}$$

where
A = ft-c (step 1)
B = number of luminaires per row
C = number of rows
D = ft-c (step 2)
E = ft-c (step 3)
F = ft-c (step 4)

Regular area with one continuous row of luminaires. (1) Divide the continuous row into four equal lengths. Opposite each of the three division points and midway between the row of units and the wall, take a reading (q). Repeat on the opposite side and average the six readings. (2) In one corner take one reading (p) as shown in Fig. 5-3c. Repeat in another corner and average the two readings.

$$\text{Average illumination} = \frac{(\text{ft-c in step 1}) \times (\text{number of luminaires per row}) + (\text{ft-c in step 2})}{\text{number of luminaires plus 1}}$$

Floodlighting Survey Procedure for Baseball and Football Field Installations.

In many floodlight installations light is projected in a direction forming a large angle of incidence with the surface to be lighted, and each unit must be adjusted carefully to produce the best utilization. This also necessitates the application of special care in the measurement of the resultant illumination. The following is a condensation of the recommended practice developed by the National Electrical Manufacturer's Association.[3]

Preparation for the survey. (1) Inspect and record the condition of the reflectors. (2) Record the mounting height of the floodlights. (3) Record the location of the poles and the number of units per pole; the wattage of the lamp; and the direction of aim. Check these data against the recommended layout; a small change in the location or adjustment of the floodlights may make a considerable difference in the resultant illumination. (4) Determine and record the hours of burning of the installed lamps. The test should be made with seasoned new lamps. (5) Record the atmospheric conditions. Because of the effect of smoke, fog, and so forth, survey should be made only when atmosphere is clear. (6) Record the voltage at the lamp socket with all lamps operating, at night during the hours when the floodlights will normally be used. A check of the voltage at the main switch or during the daytime is valueless. The light output of large incandescent lamps varies approximately 3.5 per cent with every 1 per cent change in voltage. If the measured voltage is not exactly the rated voltage of the lamp, this correction should be applied to the footcandle readings obtained before comparing them with calculated values.

Survey procedures. Measurements should be made by an experienced operator with a properly calibrated Macbeth illuminometer (Fig. 5-7*a*) or other photometer corrected for angle of incidence error. It is particularly important to see that the test plate is absolutely level whatever meter is used.* Level the test plate before taking measurements at each station.

1. Place the test plate on a firm support 24 inches above the ground and take readings at each of the test stations shown in Fig. 5-4.

Stations for the baseball field are on 45-foot centers on the infield and on 60-foot centers on the outfield. Stations for the football field are located on lines parallel to the goal line, spaced 10 yards apart. Measurements should be made at seven stations equally spaced in each line across the field. It is necessary to take readings on only one half the field.

2. At each station average three separate readings and avoid casting shadows on the plate during the reading.

* Because of the large angle of incidence at which light from a floodlighting installation usually strikes a horizontal playing field, large errors are introduced into measurements made with common types of illumination meters employing barrier-layer cells. Correction for this error must be made if such a meter is used for taking readings. The correction procedure is outlined on page 5-12. The design of the General Electric multicell color corrected diffusing plate is such that the incidence error is minimized. (See Fig. 5-5.)

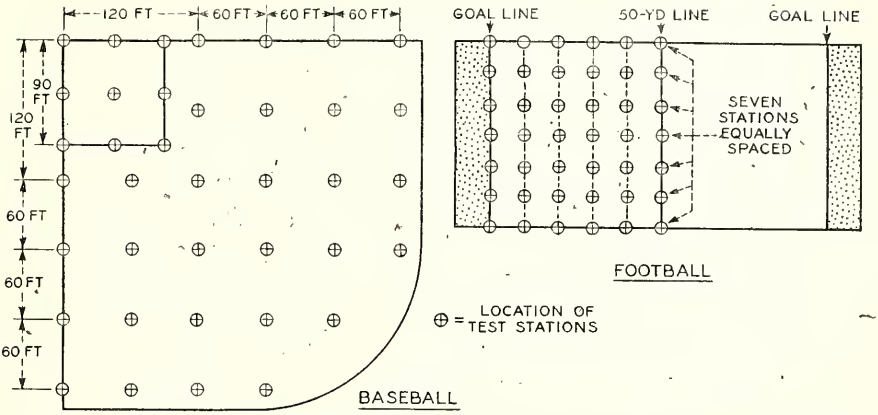


FIG. 5-4. Location of illumination measurement stations on football and baseball playing fields.

3. Check the milliammeter reading on the illuminometer frequently to ensure proper calibration. More consistent readings are obtained at the expense of frequent battery replacements if the comparison lamp is on throughout the test.

4. When readings have been completed recheck those at the first station.

Calculated footcandles. The calculated footcandles for a given installation are based upon the results of photometric tests of individual units which are accurate within plus or minus 2 per cent for the ideal conditions of the photometric laboratory. These results apply to an absolutely clean average reflector and are made under controlled conditions with new lamps selected and standardized for their rated lumen output. The lamps are operated at exactly the correct voltage to produce the rated lumen output. Despite proper application of utilization and depreciation factors in the computation, it is not possible to predict the resultant illumination produced in the actual installation with equal accuracy in every case because of uncontrollable variables encountered in the field.

A number of more or less portable photometric devices have been developed for use in the field. These must be expected to suffer the ills to which most portable devices are susceptible and therefore for reliable results must be transported and used carefully, and calibrated frequently.

Portable photoelectric photometers

The convenience and portability of photoelectric devices such as shown in Fig. 5-5 have given them preference over the visual illuminometers for lighting survey work. However, devices which utilize photoelectric cells are very likely to vary in sensitivity and may not have spectral response characteristics similar to those of the human eye. These and other characteristics are the cause of a number of errors.[4, 5]

Spectral sensitivity curve. Representative characteristics of several dif-



FIG. 5-5. Portable photoelectric illumination meters (selenium barrier-layer cell): (*a*) Weston; (*b*) General Electric; (*c*) Westinghouse.

ferent cells are shown in Fig. 5-6*a*. In 1937 the I.E.S. Committee on Photoelectric Portable Photometers recommended that barrier-layer cell photometers be calibrated by the use of unmodified radiation from an incandescent lamp source operating at a color temperature of 2,700K.[5] To correct the readings obtained with sources of other spectral characteristics, multiplying factors usually available from the manufacturer are used. Figure 5-6*b* shows the variation of multiplying factor with color temperature of calibration source and test source calculated for uncorrected cells of representative spectral characteristics.[5] For light sources commonly used in interiors, this error may vary from 5 per cent to 25 per cent.

Some cell-type instruments are equipped with filters which give the cell the approximate response of the eye and this error is thus minimized. When thus corrected, the meters evaluate sources with fairly uniform spectral emission well enough for most illuminating engineering purposes.[6,7,8,9]

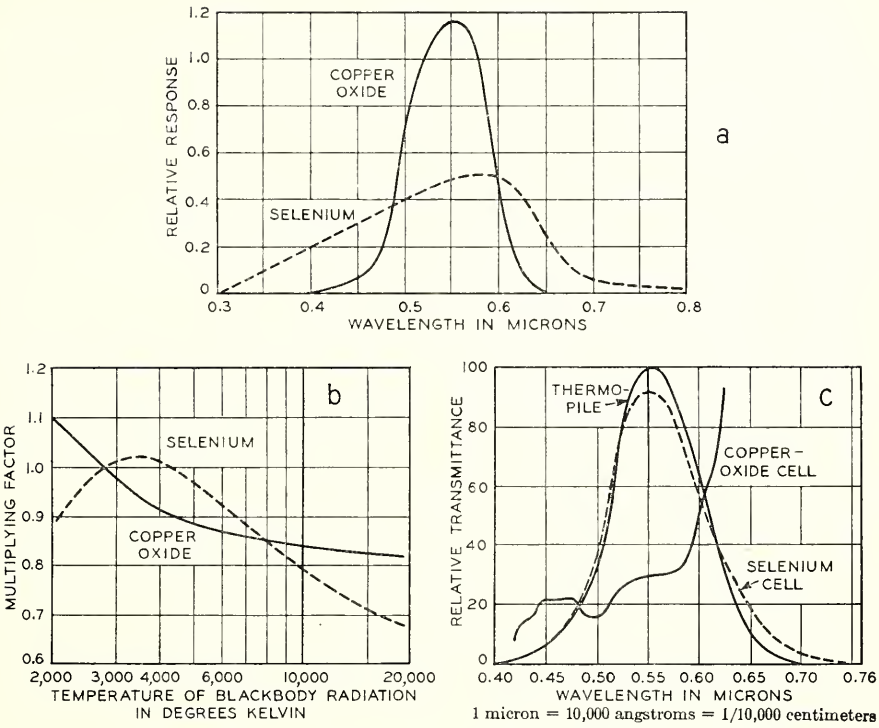


FIG. 5-6*a*. Relative spectral sensitivity characteristics of typical copper oxide and selenium barrier-layer cells. *b*. Multiplying (correction) factor versus color temperature for uncorrected cells of representative spectral characteristics.[5] *c*. Spectral transmittance curves for filters designed to correct the spectral sensitivity characteristic of barrier-layer cells and thermopiles to correspond with I.C.I. observer. "Viscor" and "Barnes" filters are designed for use with selenium cells.

Methods of measuring ultraviolet energy have been described also.[11]

Adaptation level. Like the human eye, many photocells increase in sensitivity when kept in the dark for periods extending over several hours. A normal reading can be obtained only after the cell has been adapted by exposure to the light for a period which for different instruments of the same type may vary between several minutes and several hours. The way to determine the interval for a particular instrument is to observe over a period of time the output (meter reading) of a dark-adapted cell (12 hours in the dark) when it is exposed to a constant illumination. Adaptation is complete when the readings remain constant. The cell must be exposed to each new level of illumination (variation of ± 10 footcandles) for this period before accurate readings may be obtained. The error due to lack of adaptation will not exceed about 5 per cent and therefore may usually be ignored in field work.

Angle of incidence (cosine law). Light which strikes the face of a cell is reflected from the cover glass and the cell surface, and may be obstructed by the rim of the case. The magnitude of these effects varies with the angle of incidence, and an error of the order of 25 per cent can be expected

when measuring illumination in large areas where the luminaire has a widespread light distribution and in any area where light walls, floors, and ceilings contribute an appreciable amount of flux. Multicell meters such as that shown in Fig. 5-5 are so constructed that the cosine error is nearly eliminated.[8] The Macbeth illuminometer may also be used to avoid this error.

Correction for cosine error. The component of illumination contributed by sources at large angles of incidence may be determined by orienting the target perpendicular to the directions from which the light is coming and multiplying the readings thus obtained by the cosines of the angles of incidence.

A method for correcting this cosine error by means of a special scale and shadow caster which permits the use of the cell in its normal horizontal position has been described and other means have been proposed.[5, 10]

Temperature effect. Temperature affects cell output, but not in a constant or predictable manner. To be on the safe side, the instrument should be calibrated at the air temperature of the space being investigated, preferably within the range of 60 degrees to 90 degrees Fahrenheit. Prolonged exposure to temperatures above 120 degrees Fahrenheit will permanently damage selenium cells. Hence measurements of high levels should be made rapidly to avoid overheating of the cell.

Accuracy of meter readings. The microammeter used in connection with photoelectric instruments, in common with other electrical instruments, is subject to certain inherent limitations in the form of scale errors which vary in amount with the quality of the instrument. If the instrument has more than one scale, these should be so employed that no reading is taken in the range from zero to one fourth of full scale. Neglecting the factors noted above, the manufacturing tolerances alone may result in an over-all uncertainty of reading at any point on the scale of about ± 7.5 per cent of the full scale reading.

Calibration. Cell-type instruments have no provision for field calibration other than a zero reading correction. They should be checked frequently against a master instrument of known calibration or returned to a reliable laboratory at frequent intervals for calibration.

Portable visual photometers

The portable photometer or illuminometer is a bar photometer on a small scale. There are a number of different types available but the underlying principles are about the same. A fixed photometer head and moving comparison lamp is often used and some are combined with a photoelectric photometer.

When using the portable photometer to measure illumination, it is customary to observe the brightness of a calibrated test plate. For brightness determinations, the field to be observed is seen directly through the eyepiece, and balanced with the comparison surface. This type of photometer is usually accompanied by a set of neutral and colored filters, which respectively extend the range and produce an approximate color

match between the test and the comparison surfaces. The color filters usually should be placed between the comparison lamp and the comparison surface.

The *Macbeth illuminometer*, shown in Fig. 5-7*a*, consists of a Lummer-Brodhun cube, eyepiece, and comparison-lamp tube. Though less compact and more complex in its application than the photocell-type meters,

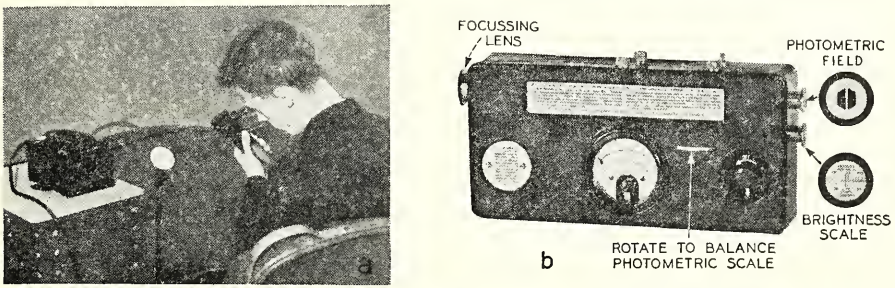


FIG. 5-7*a*. The Macbeth illuminometer. *b*. The Luckiesh-Taylor brightness meter.

it is self contained in a carrying case and is a portable instrument. A diffusing-glass comparison surface (viewed by transmitted light) is illuminated by a lamp in a diaphragmed enclosure which is moved in the comparison-lamp tube by a rack and pinion. The illuminometer may be equipped with a lens to bring into focus and restrict the test field. An inverse-square scale is marked upon the rod moving the comparison lamp. Provision is made for inserting neutral filters by which the range of the instrument is made to cover 0.001 footcandle to 10,000 or more footcandles. A control box carrying rheostats and a meter on top, with a compartment below for two No. 6 dry cells, is regularly furnished along with a diffusing test surface and a reference standard for recalibration. The reference standard consists of a lamp in a housing having a hole for insertion of the sight-tube so that the test-surface may be viewed. The illumination incident upon the test-surface when a predetermined current is passed through the lamp is known and serves as the basis for calibrating or checking the readings of the illuminometer. Since the luminous reflectance of the test-surface is known or determinable, for normal illumination and observation in the 45- to 55-degree zone the reference standard also serves to calibrate the instrument for readings of brightness in footlamberts (the product of the illumination, i.e., footcandles, by the luminous reflectance of the test-surface).[12] This instrument is capable of measurements uncertain by only about ± 1 per cent when used by an experienced observer.

The *Luckiesh-Taylor brightness meter*, shown in Fig. 5-7*b*, is entirely self contained. The batteries fit into the case which has a control rheostat and scale on the side. The current is set for the calibration mark and maintained at that mark while measurements are being made. There is a

lens for focusing the light from the source and an eyepiece for viewing the photometric field. The optical system presents a split field with the test field in the center and the comparison fields on either side. The comparison-field brightness is adjusted by turning a knob. When a photometric balance has been obtained, the reading is seen on an illuminated scale viewed through a magnifier located just below the eyepiece. Neutral filters extend the range. In the hands of an experienced observer photometric balances can be reproduced with a variation of 1 or 2 per cent; scale and filter errors are usually somewhat larger.[13]

Miscellaneous field equipment

Reflectometers. The Taylor reflectometer, and the General Electric light cell reflectometer shown in Fig. 5-8 are similar instruments. The former is designed for visual measurements (normally equipped with an opening for a Macbeth illuminometer). The latter makes use of the barrier-layer cell as the measuring device. Both are small portable spheres with a surface opening for the test sample. A collimated beam is incident on the sample at about 45 degrees and the total reflected light is integrated by the sphere. The tube carrying the light source and the collimating lenses can be rotated so that light is incident directly on the sphere wall for the unreflected or 100 per cent reading. The sample is in place during both measurements and thus may be considered a part of the sphere so that the effect on both readings of the small area it occupies is the same. The ratio of the reading when light is incident on the sample, to the reading when the light is incident on the sphere wall is the luminous reflectance for the conditions of the test. The light cell reflectometer is designed to be used also with another sphere source giving diffuse illumination for measurement of luminous transmittance as shown in Fig. 5-8. The transmittance thus determined is the total transmittance for diffuse incident light.[14]

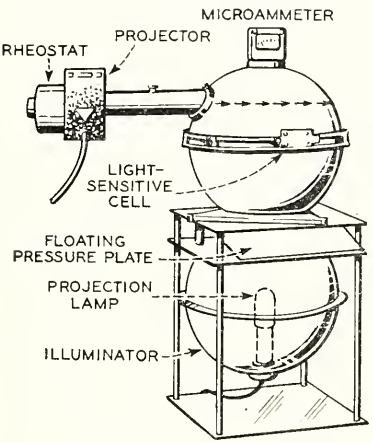


FIG. 5-8. The General Electric light cell reflectometer showing arrangement for transmittance measurements.

The *Luckiesh-Moss visibility meter* shown in Fig. 2-14 on page 2–16 is used to determine the visibility of an object or task.

Laboratory measurements

Because many of the variables encountered are uncontrollable and therefore limit the accuracy and precision of field measurements, more reliable data may usually be obtained in the laboratory. Therefore whenever it is at all convenient photometric measurements should be made in a laboratory properly planned and equipped for this work.

Most laboratories well equipped for general photometric work make use of the following basic types of equipment:

Bar photometer.
Integrating sphere.
Distribution (gonio) photometer.

In order that uniform results may be obtained by different laboratories, the Illuminating Engineering Society has developed standard procedures for several types of measurements:

Diffuse enclosing-globe luminaires[15].
Semi-indirect enclosing-globe luminaires[15].
Direct luminaires[15].
Indirect luminaires[15].
Semi-indirect luminaires[15].
Narrow-beam enclosed projectors[16].
Incandescent filament floodlights[17].

Each of these procedures, which are combined here for handbook explanation, have been discussed in detail in the references indicated. While the handbook condensation is in agreement with the original in each case, it is recommended that the detailed reports be studied for additional guidance.

General. The tests shall be conducted by a reliable laboratory which certifies by its signature that the tests have been conducted in accordance with the I.E.S. specifications and that the data are accurate. A prominent note to the effect that the test results are typical only when all test conditions such as light center position and so forth are reproduced should be included. A standard illuminating engineering data form will be made available by the Society for reporting tests on general illumination luminaires.

DATA TO BE REPORTED

Manufacturer's name.
Name or type of luminaire.
Manufacturer's catalog numbers.
Number of samples submitted (minimum of six).
Lamps:
 Type.
 Number per luminaire.
 Watts each.
 Total watts including auxiliary control equipment.
 Volts, bulb size, base, service, filament construction, color, type of bulb glass.
 Light center.
 Rated lumens each.
 Power factor.
Description of luminaire:
 I.E.S. classification.
 Applicable I.E.S. performance recommendations.
 Materials.
 Luminous reflectance and/or transmittance.

Dimensions including husk and stem; may be given on dimensioned scale drawing. (See Fig. 5-9*a*.)
Light center position during test.
Distance from cap of lamp base to plane of fitter screw.
Weight, also maximum and minimum weights of six samples tested.
Method used for standardizing lamp and for calibrating photometer.
Candlepower distribution, brightness, and light flux values as in Fig. 5-9*b*.
Total lumen output (in terms of bare lamp lumens).
Testing distance.
Description and explanation of any deviation from standard test conditions or procedure.
Total efficiency.
Permissible spacing ratios (relative to mounting height). (See page 8-22.)
* Maximum beam candlepower as recorded in prescribed beam exploration.
* Average maximum beam candlepower.
* Beam spread in degrees in vertical and horizontal directions.
* Outline of the beam. (See Fig. 14-4c.)
* Tabulation of lumens for test area explored.
* Beam efficiency.
* Average lumen distribution in beam.
* Beam lumens.
* Average isocandle curves.

Selection of luminaires for test. Six samples should be selected at random from stock and weighed. The lightest, the heaviest, and the three samples closest to average weight should be selected for the over-all light output test. The sample having the output closest to the average of the five should be used for all other tests and should be the unit to which the descriptive data reported apply.†

Preparation for photometric tests. As many as possible of the variables which may introduce error into the results of the tests should be eliminated or minimized. Dust, grease, and so forth should be removed from all optical surfaces of lamp, luminaire, and apparatus. Stray light should be eliminated and all mechanical components should be in smooth working order. A new lamp of the type required for the test should be selected. This should be well constructed and free of any obvious defects, ready for seasoning.

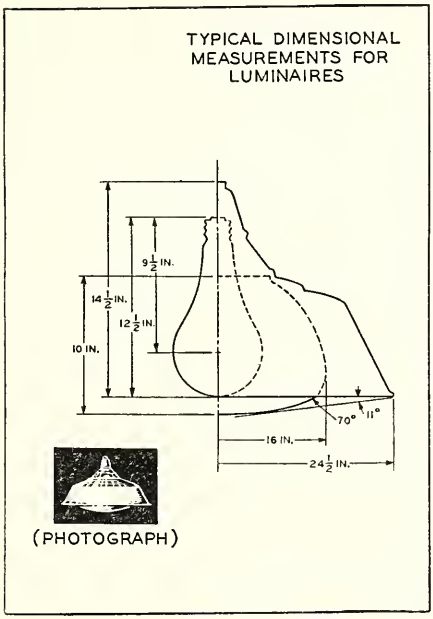
Calibration of lamp and photometer. An acceptable lamp of the desired size and service should be seasoned and calibrated at a definite current value. It should also be calibrated for intensity in a horizontal direction, as indicated by permanent orientation-reference markings (fiducial lines) placed on the bulb.

The calibration data of the lamp consist of three items:

Manufacturer's light output rating in lumens.
Fiducial intensity in candlepower.
Input in amperes and volts.

Having the fiducial intensity in candlepower and the rated output in lumens, the numerical ratio between the total bare lamp output in lumens and the intensity in the marked direction is independent of the current

* For projector-type luminaires only.
† This method of test luminaire selection is applicable particularly to types with diffusing glass ware.



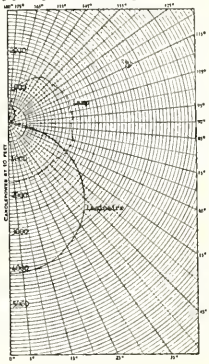
a

PHOTOMETRIC DATA

LAMP: 1000 Watts; 120 Volts; 21000 Lumens; PS52 Clear Bulb
Tungsten; Equal Rated General Service.
LUMINAIRE: HI-LIGHT GLASSTEEL DIFFUSER - JOHN DOE CATALOG NO.000
Reflector - Inside surface porcelain enamel; Reflection factor 0.795; specified min. 0.765; mean 0.79.
Globe - Opal diffusing glass globe; maximum brightness at 0°.

LUMINAIRE DISTRIBUTION DATA

MID-ZONE ANGLE	CANDLE POWER	ZONAL LUMENS
180	515	
175	497	47
165	435	123
155	433	201
145	343	215
135	263	204
125	201	180
115	138	133
105	76	81
95	38	41
90	121	
85	296	323
75	850	901
65	1610	1578
55	2330	2126
45	2930	2267
35	3410	2142
25	3780	1751
15	4010	1134
5	4140	393
0	4150	



LUMINAIRE LIGHT FLUX VALUES

ZONE	LUMENS	% TOTAL BARE LAMP
0-30°		
0-40°		
0-60°	9815	47
0-90°	12637	60
90-180°	1229	6
0-180°	13866	66

TOTAL LAMP LUMENS 21000
EFFICIENCY OF LUMINAIRE 66

MAXIMUM BRIGHTNESS OF LUMINAIRE IN FOOTLAMBERTS

ZONE	ANGLE OF MAXIMUM	SIDES *	END
0°	0°	7175	
0-30°			
30-60°			
60-90°			
70°		4750	

* AVERAGE FOR SYMMETRICAL DISTRIBUTION.
SOURCE OF TEST DATA: LABORATORY Independent TEST NO. 000
DATE Sept. 1936 TESTED BY Doe APPROVED BY Jones

b

FIG. 5-9*a*. Page from standard I.E.S. report form showing dimensioned scale drawing and photograph. *b*. Distribution data presented on standard I.E.S. Form.

or voltage at which the lamp is held. This is the basis of the following method for obtaining the output and distribution characteristics of the luminaire.

The lamp can be used as an absolute standard of intensity, but for the purpose of these tests it is better to use it as a combined standard and test lamp. The lamp is held at a definite current value rather than voltage value throughout the test to eliminate possible errors due to socket drop or faulty electrical connections.

The lamp is first used to calibrate the photometer with which the luminaire is to be tested. Since the intensity of the lamp in the marked direction is related by a fixed numerical ratio to the total output of the lamp in lumens, regardless of the current at which the lamp is held, it is possible to calibrate the photometer by light received from the bare lamp in the marked direction, as though the lamp was operated to give rated intensity. Since the lamp is held at the same current throughout the standardization and the test, luminaire characteristics determined will be the same as if the lamp were held at rated lumen output throughout the test.

Any ammeter of good constancy and giving a large scale deflection for the current measured is satisfactory. The exact meter calibration need not be known. In general, it is best to hold the current about 5 per cent less than the calibration current in order to ensure minimum change of light output from the lamp during the test. The selected current must

be carefully maintained throughout the test. By calibrating the photometer directly against the test lamp, regardless of the exact candlepower at which the lamp is held, illumination values are obtained in terms of the standardization values of the lamp.

The standard lamp is placed at a measured distance D (feet) from the photometer head, so that the illumination received by the photometer plate is that established by the fiducial lines on the bulb. The assumed illumination is then

$$E = \frac{I}{D^2} \text{ footcandles}$$

where I is the standardized fiducial intensity in candles. This value of E is used to find the scale constant C of the photometer. When the scale reading is S,

$$C \times S = E$$

The standard lamp is then adjusted in the luminaire and connected with the same ammeter as used for the calibration. The photometric test is carried on at the selected current.

The actual values of light output and beam intensities under these conditions will be smaller than they would be if the lamp were operated at normal rating, but this method of calibrating the photometer exactly compensates for the difference, and the photometer readings times the constant C give values correct for rated lumens output.

Adjustment of lamps in the luminaire. The exact position of the light center of the lamp in the luminaire is extremely important in the case of projector-type devices such as floodlights and searchlights and may exert a considerable influence on the characteristics of general lighting luminaires. Therefore, before making any photometric measurements, the lamp should be carefully adjusted in the luminaire.

For *projector-type* luminaires the focusing of the lamp is to be done at a distance of 100 feet or more from the observing screen, and at the same distance at which the photometer readings are to be taken. The lamp should be adjusted to give the narrowest uniform and symmetrical beam.*

Whenever the adjustment of the lamp in a projector-type luminaire is not fixed by the design or specified by the manufacturer, the lamp shall be adjusted as follows: (a) The filament opening of a ring-type filament, such as the C-5 or C-7A, shall be toward the front or up. (b) The lead wires of a monoplane-type filament, such as the C-13, shall be placed parallel to the plane of the reflector opening and away from the reflector.

For *general lighting luminaires* in which there is provision for adjustment of the light center of the lamp, the position should coincide with that stated by the manufacturer or shown on the manufacturer's plan.

Photometric tests for general lighting luminaires. If the luminaire is regularly sold or recommended by the manufacturer to be used with a particular fitting such as a support, the fitting should be attached during

* Unless another working focus is specified.

the test and described in the report. If no such device is provided or recommended in the manufacturer's literature, the following conditions shall apply: (a) For enclosing globes, the opening shall be covered by a material having a neutral tint, a mat surface, and a luminous reflectance of 30 per cent to 40 per cent; no other reflectance is acceptable. The report shall state the exact value of the reflectance. (b) The cap-contact position (i.e., the distance from the cap-contact of the lamp to the plane of the fitter screw) shall be $1\frac{1}{2}$ inch for the 4-inch fitter, 2 inches for the 6-inch fitter, and 3 inches for all mogul-base lamps, unless some other position is specified by the manufacturer of the globe and is stated in the report.[15]

The *total lumen output* of each of the six samples shall be measured in a sphere or by an equivalent method. (See page 5–26.) The results shall be stated in the report as the per cent of total bare lamp lumens.

The candlepower distribution characteristics of the sample whose lumen output is closest to the average output of the heaviest, the lightest, and three of average weight shall be determined: (a) the candlepower at 0 degree of the bare lamp and the luminaire, (b) the candlepower of the rotating luminaire at 5 degrees, 10 degrees, 15 degrees . . ., and 175 degrees.

Note: If it is not feasible to rotate a luminaire with symmetric distribution, readings should be made in at least eight planes and averaged. Measurements should be made in planes spaced at not less than 5-degree intervals for those luminaires with asymmetric distributions.

The *test distance* in all cases shall be not less than 10 feet, or five times the maximum dimension of the luminaire, whichever is larger.[19]

The *maximum brightness* of the luminaire in footlamberts in each of the following zones (at both sides and ends where asymmetric) shall be determined with a suitable photometer: 0 degree, 0 degree–30 degrees, 30 degrees–60 degrees, and 60 degrees–90 degrees. The angle at which the maximum occurs shall be recorded in each case. The photometer or diaphragm should be so adjusted that the projected area observed is approximately one square inch. When there is symmetry in a zone, the luminaire should be rotated during the measurements.

Photometric tests for projector-type luminaires. The whole aperture of projector-type luminaires such as locomotive headlamps, aircraft landing lamps, airway beacons, floodlights, and searchlights is usually filled with light and appears equally bright all over. This aperture area is therefore the source for photometric purposes. Measurements are expressed in terms of apparent candlepower measured at a specified distance. It is common to determine maximum apparent beam candlepower, lumen output in the beam, and angular beam spread (both horizontal and vertical).

Mounting luminaire. So that the directions of the beam may be adjusted vertically or horizontally or in both directions at will, the luminaire should be so mounted that the beam can be adjusted in accurate vertical and horizontal steps not greater than 0.1 degree.

Test distance. Accurate results in testing projector-type luminaires can be obtained only if the test distance is adequate. A minimum range of 100 feet is recommended for floodlights, and for searchlights much greater distances are often necessary as indicated by Fig. 5-10.

Test procedure. Beams produced by projector-type luminaires are likely to be nonuniform in intensity. Traces of filament images are almost always detectable and, particularly in the case of devices which utilize carefully figured specular mirrors, the images may be quite sharp. Errors may be caused by these filament images if individual photometric observations cover too small an area at the proper test distance. A device such as a sphere, diffusing screen, or test plate capable of integrating the illumination of a square subtending one degree on each side may be used to minimize these errors. (*Note:* 20.94 inches subtends one degree at 100 feet.)

The luminaire should be adjusted in ten equal angular steps in each of ten equally spaced vertical or horizontal planes. The spacing should be planned so that the maximum beam candlepower is approximately centered and so that 10 per cent of maximum is just within the area covered. The illumination should be measured for each of the 100 settings and plotted on rectangular co-ordinates as shown in Fig. 14-4c. The candlepower in the beam may be computed using the zonal constants found in Appendix Table A-31, page A-47.

Correction for atmospheric transmission. The absorption of light by moisture, smoke, or dust particles even in an apparently clear atmosphere may introduce considerable errors in measurements made at test distances greater than 100 feet.[16,20] It is therefore desirable to measure the atmospheric transmission before and after the test has been made. This may be done by measuring the illuminations at two distances (500 feet and 1,000 feet, for example). When the absorption is not great an approximate correction can be calculated by assuming that the difference between the two values of candlepower computed by means of the inverse-square law, divided by the difference in distance, equals the absorption per foot.

General Photometric Methods

Substitution. By the use of the substitution method, in which a third source whose luminous intensity must be constant (but need not be known) is used as a comparison lamp on one side of the photometer head while sources to be compared are placed in turn on the other side, the luminous intensity of the comparison lamp is cancelled out and the ratio of test source candlepowers is obtained independent of any lack of symmetry in the photometer. Usually, the distance between the photometer head and comparison lamp is fixed, so that the brightness of the comparison surface is constant.

Heterochromatic visual photometry. Close attention to detailed photometric procedure is required in the photometry of discontinuous spectra such as are produced by discharge sources.

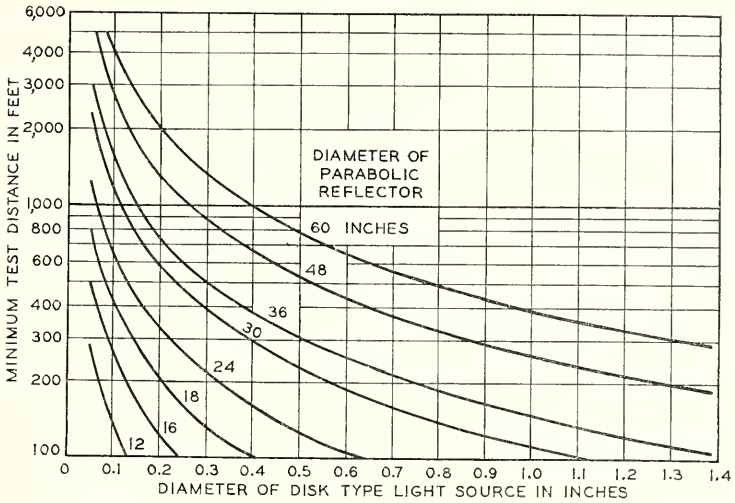


FIG. 5-10. Relationship between minimum photometric test distance, light source diameter (disk type), and parabolic mirror diameter (12-inch to 60-inch) for accurate measurement of central intensity in a searchlight beam.

It is necessary to standardize the observing conditions so that results are reproducible. As far as possible, the conditions under which the visibility data defining the standard observer were obtained should be duplicated. A small field is required to limit observation to the macula, a small sensitive region near the center of the retina filled with closely packed cones, the light sensitivity of which corresponds approximately to published visibility data. The rods found in the regions surrounding the macula are relatively more sensitive to weak illumination and they have a peak light sensitivity at shorter wavelength than the photopic or standard sensitivity. These differences between the location and the brightness sensitivity of the retinal rods and cones give rise to the Purkinje effect and may lead to serious photometric errors if overlooked. (See page 2-3.)

These problems are important whenever sources such as the mercury, sodium, or neon lamps are to be photometered, and methods have been developed whereby good results may be obtained through the use of color filters.[21] It has been found that amber filters can be designed to match sunlight, daylight, or skylight with tungsten source illumination. The light from the Welsbach mantle is matched by tungsten illumination modified by a light green filter. Carbon arc lamps can be photometered with the aid of amber filters on the test side or blue filters on the comparison side. Blue-green radioactive luminous materials can be color-matched with tungsten by means of a blue-green filter on the tungsten side. Filters may also assist in the visual photometry of fluorescent sources.

All exact or approximate color-temperature colors can be matched by the use of color-temperature-altering filters and by the adjustment of the

comparison lamp color temperature. The design and selection of such filters has been described.[22] These filters are rated in terms of their color temperature altering power; which, for convenience in computing, is developed on the scale of reciprocal color temperature on which the customary unit is the micro-reciprocal degree, abbreviated for convenience to "mired." One mired is about the smallest observable color temperature difference and the customary scale ranges from 50 mireds (20,000 degrees) to 1,000 mireds (1,000 degrees). The Macbeth illuminometer has a comparison lamp which can be conveniently adjusted from about 410 mireds (2,440 degrees) to 470 mireds (2,130 degrees). Through the use of a series of color temperature raising and lowering filters covering the entire scale with the interval between any two adjacent filters less than 60 mireds, sources throughout the whole range of color temperature can be photometered. If a specific color temperature is desired the Davis-Gibson filters can be prepared.[23]

Because the use of filters with sources having a widely different energy distribution produces only a psychological color match, the procedure by which standard and test lamps are in turn photometered against a comparison lamp is not a true substitution method and therefore is not a satisfactory safeguard against photometric error. The transmittance and reflectance of various components of the photometer are usually different for the test, standard, and comparison source energy distributions. In fact, the eye itself is not symmetrical in light sensitivity about its optical axis, and for the most precise measurements it may be necessary to rotate the photometer about its vertical axis so as to interchange the positions of the field images on the retina. When this procedure is followed, the average of the two sets of readings should be used.

The magnitude of the necessary corrections for variable absorption can be reduced by taking steps to ensure that the photometer is as nonselective in its absorption characteristics as possible.

The test plate reflectance should also be nonselective, having as high reflectance as practicable conforming closely to the cosine law of perfect diffusion. White opal glass and white blotting paper make reasonably good test plates with luminous reflectance of approximately 80 per cent. The blotter may introduce a small specular error and is more likely to be soiled. Observations should be made normal to the test plate. When this is not possible, the reflectance characteristics of the plate should be determined in advance and readings at the angle of reflection of the principal sources should be avoided.

For *measuring the color temperature* of light sources, color temperature standards have been made available both by the National Bureau of Standards* and by the Electrical Testing Laboratories.† Comparisons with them may be made either visually by matching the test lamp against the standard, or, photoelectrically, by comparing the red-to-blue ratio of the test lamp with that obtained for the standard using the same filters.

* Washington, D.C.
† New York, N.Y.

Photometric Instruments and Their Use

Photometry dates back to the early 1700's. Bouguer in 1729 first compared two sources (one a reference standard) by allowing their light to fall upon two contiguous white surfaces, each receiving the light from only one source. Either one or the other source was moved until the brightnesses of the two surfaces appeared to be the same.

The *Bunsen disk* consists of a translucent paraffined spot in the center of a substantially opaque white paper flanked by two mirrors forming an angle of 90 degrees bisected by the paper. From a point in the plane of the paper, images of both sides of the paper formed by the mirrors can be seen at one time. With the light sources placed on either side of the disk, a photometric balance is made by comparing the two reflected images of the paper. To secure a balance the distance from one or both light sources to the disk is adjusted.

The *Leeson disk* is a star cut in white opaque paper covered with thin tissue paper. In all other respects it is the same as the Bunsen disk but provides slightly increased accuracy.

The *Lummer-Brodhun cube* consists of two identical 45 to 90 degree prisms with a pattern (usually a small circle) etched in the hypotenuse face of one. The two hypotenuse faces are pressed together to make optical contact. Where the surfaces are in optical contact, light is transmitted, thus presenting an opportunity to compare two fields. More accurate results may be obtained than with either Bunsen or Leeson disks.

The more precise *contrast Lummer-Brodhun cube* is a refinement over the simple cube. With the simple Lummer-Brodhun cube a photometric balance (brightness match) is secured when the two fields illuminated by the standard and the test source, respectively, merge and the lines of demarcation disappear. In the contrast cube, a balance is secured by matching one contrast field centered in an outer field with another contrast and outer field. The contrast fields are in the center of each of the simple fields and their brightness is about 8 per cent less than the brightness of the simple fields. This arrangement results in slightly increased precision; however, it is necessary to use very closely color matched standard and test sources if precise results are to be obtained.

The *flicker photometer* was the first instrument by means of which sources not identical in color could be compared satisfactorily.[25] Its use is complicated by the fact that a color response calibration must be determined for each different observer. Also, the test and comparison fields must be surrounded with a brightness substantially equal to the test field brightness. Quite accurate determinations of intensities from light sources of different color characteristics are obtainable with this instrument.

The *Marten's polarization photometer* is a laboratory device designed to operate in accordance with the tangent-squared law of polarization. This involves the production of polarized images of two surfaces by means of a Wollaston prism. The images are polarized in planes perpendicular

to each other. An analyzing Nicol prism interposed in the path of these beams will reduce one image by the factor $\cos^2 \theta$ and the other by the factor $\sin^2 \theta$, where θ is the angle between the polarizing plane of the Nicol prism and the plane of polarization of the light forming the first image (plane of polarization of the ordinary ray transmitted by the Wollaston prism). If θ is the angular position for a photometric balance, the ratio of the brightnesses of the two images, with no Nicol prism interposed, would be $\tan^2 \theta$.

The *physical photometer* has been available since about 1925. Three types are common: the barrier-layer cell which generates a current when exposed to light, the resistance cell which changes its resistance when exposed to light, and the phototube of which saturation current at any voltage is a function of the illumination. A thermopile photometer also has been developed.[9] Some cells have undesirable lag and fatigue characteristics.

A wide range of sensitivities and responses may be secured through the use of either resistance cells or photoelectric tubes. For short wavelengths, such as the ozone-producing region around 0.185 micron, platinum phototubes can be used. For the germicidal range around 0.25 micron, tantalum or tungsten phototubes can be used. For the erythemal band, sodium cells are available, and in the infrared, silver cesium oxide and thallous sulphide tubes are useful.

A *sector disk* with an adjustable angular aperture can be rotated between a source and a surface so that the light from the source reaches the surface for only a certain fraction of the time, and if the rotation is so fast that the eye perceives no flicker the effective brightness of the surface is reduced in the ratio of the time of exposure to the total time (Talbot's law). The reduction is by the factor $\theta/360$ degrees, where θ is the angular aperture in degrees. The sector disk has advantages over many filters in that it is not affected by a change of characteristics over a period of time and reduces total luminous flux without changing its spectral composition.

Neutral filters are not readily obtainable. Wire mesh or perforated metal filters although perfectly neutral have a limited range. Mirrored filters have high reflectance and the reflected light must be controlled to avoid errors in the photometer. Also, it is difficult to secure completely uniform transmission over all parts of the surface.

So-called neutral glass filters are seldom neutral. In general, they have a characteristic high transmission in the red region and low in the blue. This may be reasonably well corrected by the use of two layers of glass, one of the most neutral glass available and the second yellow-green which absorbs in the extreme red. However, this type of filter has a transmittance characteristic curve which varies with ambient temperature as do the curves for many other optical filters.

The "neutral" gelatin filters are quite satisfactory, though not entirely neutral and some have a small seasoning effect, losing neutrality over a period of time. These must be protected by being cemented between two glass surfaces and watched carefully for loss of contact between the glass and gelatin. Any separation changes the transmittance characteristics.

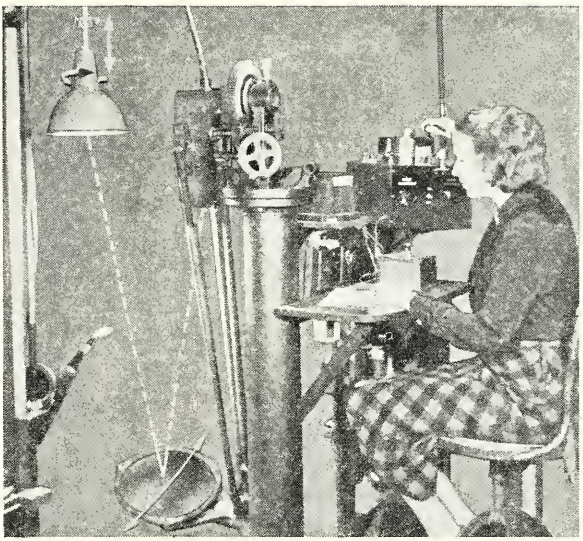


FIG. 5-11. Distribution or gonio photometer used at the Electrical Testing Laboratories for obtaining candlepower distribution curves. The luminaire mount is so arranged that symmetrical luminaires may be rotated about a vertical axis during the measurements.

A *distribution* (*gonio*) *photometer* such as that shown in Fig. 5-11 is used to determine the candlepower distribution curve of light sources and luminaires and the reflectance characteristics of materials.[26] Many have provision for rotating the source (or placing it in various orientations) and carry one or more mirrors on arms moving about the source as a center. The "candlepower distribution curve" and the total flux of luminaires may be determined by measuring the luminous intensity at the middle of each 10-degree zone from 0 to 180 degrees; angles customarily being measured counterclockwise with the nadir or zero at the bottom or "six o'clock" position. If, then, the mean mid-zone luminous intensity* for each 10-degree zone is multiplied by a zone factor, which is the zonal area on unit radius sphere, total lumens for any zone or the complete sphere (total flux) can be computed as can the efficiency of the luminaire. Zone factors are given in Appendix Table A-30 page A-45.

Several integrating (*sphere*) *photometers* have been constructed but the one most generally used is the Ulbricht sphere of the type shown in Fig. 5-12. These have been used in dimensions from an inch or so to 15 feet in diameter. The size is principally a matter of convenience. With proper precautions and corrections, a small sphere can be quite as accurate as a large one. A cube or octahedron has also been used. The limiting minimum dimension is the size of the luminaire, and the correction decreases as the size increases.[27]

* In some cases mean zone intensity may occur at other than mid-zone angle.

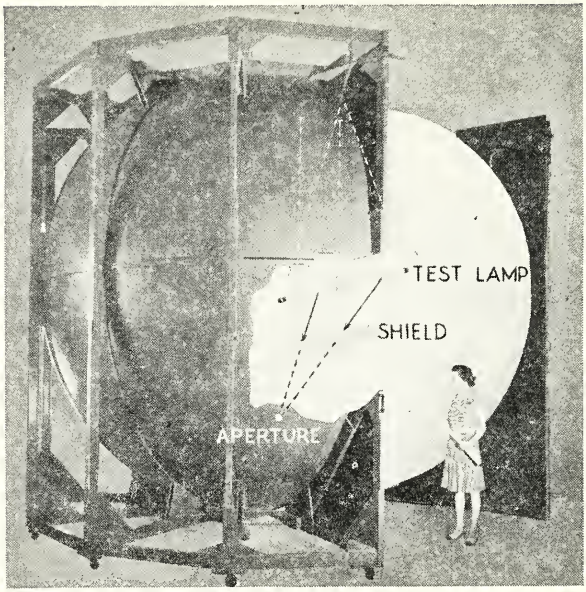


FIG. 5-12. Fifteen-foot integrating (Ulbricht) sphere used at the National Bureau of Standards.

A hollow sphere with a diffusely reflecting inner surface integrates light, either from a source within the sphere or from a beam projected through an aperture into the interior. Every part of the sphere reflects to other parts of the sphere. Therefore, there are two components of light, that direct from the source and that *reflected* from the sphere wall. If the light *direct* from the source is cut off, then the reflected light is proportional to the total light output of the source. The brightness of a small area of the sphere wall, or the brightness of the outer surface of a diffusely transmitting window in the sphere wall, is compared with that of a comparison surface by means of a photometer. Alternative methods are to measure the illumination of a test-surface a fixed distance from the outer surface of the sphere window or of a test-surface built into the inner surface of the sphere wall. The window or area is screened from direct light from the source, but receives light by reflection from the other portions of the sphere. The various elements of uncertainty entering into the considerations of a sphere as an integrator make it undesirable to use a sphere for the absolute measurement of flux but do not detract in the least from its use when a substitution method is employed.

Spectrophotometers

In spectrophotometers the light is spectrally dispersed by a device such as a prism or grating. (See Fig. 4-14, page 4–25.) Incorporated in the instruments is a visual or photoelectric photometer by means of which the reflectance or transmittance of the test material at each of many nar-

row wavelength bands is determined. The reflectance or transmittance for light of known spectral distribution may then be calculated by use of the luminosity factors for the "average eye" (standard I.C.I. observer).

The factor is computed from the relation

$$R = \frac{\Sigma\, U_\lambda\, K_\lambda\, R_\lambda}{\Sigma\, U_\lambda\, K_\lambda}$$

where R is the desired luminous reflectance, and U_λ is the energy of wavelength region λ, incident on the sample K_λ is the standard luminosity factor for wavelength λ, and R_λ is the reflectance as determined by a spectrophotometer for wavelength λ. The summation is usually carried out in every 0.01-micron band from 0.380 to 0.760 micron.[28]

Electrical Measurements

It is often necessary to determine certain electrical characteristics of light sources and accessories in connection with photometric measurements. The following are the measurements most commonly encountered. If additional information is required the reader is referred to one of the many texts or handbooks on electrical engineering.[29]

Power: (*1*) *Direct-current circuits.* Power is the product of the voltage and the current. It may be measured by using a voltmeter and ammeter or by using a wattmeter.

The ammeter or current circuit of the wattmeter is connected as shown in Fig. 5-13*a* at A and the voltmeter or voltage circuit of the wattmeter is connected as shown at V. With the switch S open the reading of the ammeter or wattmeter is taken. With the switch S closed readings of both ammeter and voltmeter or of the wattmeter are taken. The readings with S open give the current taken by the voltmeter (when using ammeter and voltmeter) or the power taken by the wattmeter voltage circuit. The readings with S closed give the current taken by the voltmeter plus the load current (when using ammeter and voltmeter) or the power taken by the wattmeter voltage circuit plus the load power.

The power taken by the load is then

$$(I - I_v)\, E = W_L \text{ for ammeter-voltmeter method, or}$$
$$W - W_v = W_L \text{ for wattmeter method,}$$

where I is the ammeter reading with S closed (the current through the voltmeter plus the load current); I_v is the ammeter reading with S open (the current through the voltmeter); E is the voltmeter reading; W is the wattmeter reading with S closed (the power taken by the wattmeter voltage circuit plus the power taken by the load); W_v is the wattmeter reading with S open (the power taken by the voltage circuit of the wattmeter); and W_L is the power taken by the load.

A *compensated wattmeter* is one that is so designed that the current through the compensating coil produces a torque equal and opposite to that produced by the power taken by the wattmeter. The current and

voltage circuits must be connected as shown in Fig. 5-13*a*. As a check on the correctness of connections the compensated wattmeter should read zero when S is open (i.e., the load is not connected).

Power: (2) Alternating-current circuits. The power (W) in an alternating current circuit is the triple product of the voltage (E), the current (I), and the power factor ($\cos \theta$):

$$W = EI \cos \theta$$

If the power factor is known, the procedure just outlined for direct-current measurements may be followed (using instruments designed for alternating-current operation). When the power factor is not known, the ammeter-voltmeter method can not be employed. Alternating-current wattmeters, however, will indicate the power.

Power factor. If an alternating-current wattmeter is not available a voltmeter may be used to determine the angle θ of which the cosine equals the power factor. The circuit is given in Fig. 5-13*b*. Simultaneous readings are taken on three voltmeters or readings in rapid succession on a single voltmeter. R is an auxiliary noninductive resistor chosen to give a reading of about or above one quarter full scale. The readings are then used to determine graphically the angle θ. By convention V_1 is drawn horizontally, the length being proportional to the voltmeter reading V_1. An arc of radius proportional to V_2 is drawn with the right-hand end of V_1 as a center, and an arc of radius proportional to V_3 is drawn with the left-hand end of V_1 as a center. These arcs intercept at some point B. V_1 is extended to the right. The angle BAC is then the desired angle θ, called the angle of lead or lag or simply the power factor angle. The cosine of θ is determined from tables or by taking the ratio of the length of AC to the length of AB.

Voltage. The voltmeter should be connected as close to the load, (or circuit component) to be measured as possible to avoid including in the measured voltage any voltage drops in other parts of the circuit. A voltmeter connected as shown by the dashed lines in Fig. 5-13*c* measures the voltage across the load plus the voltage drop across the resistor R, whereas one connected as shown by the solid lines measures the voltage across the load alone. Voltmeters are connected "across the line," that is, in parallel or shunt connection with the circuit to be measured.

Current. The ammeter should be connected in series with the load of which it is desired to measure the current. An ammeter connected as shown by the dashed lines in Fig. 5-13*d* will measure the sum of the current in the dashed-line load and that in the solid-line load, whereas, one connected as shown by the solid lines measures the current to the solid-line load alone.

Ammeters *are not connected across the line.* They are to be connected *in series* with the load.

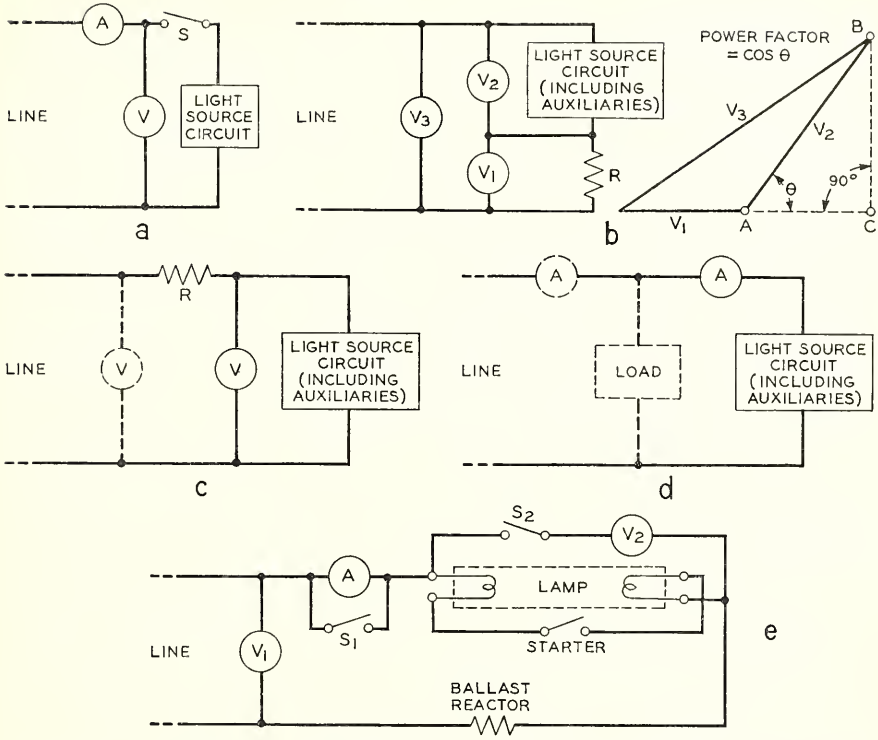


FIG. 5-13*a*. Meter connections for measurement of power in light source circuits. *b*. Method of connecting three voltmeters and graph for determining power factor of a lighting circuit. *c*. Voltmeter connections for measurement of volts in light source circuits. *d*. Ammeter connections for measurement of current in light source circuits. *e*. Test circuit for preheat-starting (hot-cathode) type fluorescent lamps.

Test circuit for fluorescent lamps. The circuit shown in Fig. 5-13*e* is a convenient arrangement for determining the electrical characteristics in a preheat-starting (hot-cathode) type of fluorescent-lamp circuit.

Precautions. Only one meter at a time is to be connected in the lamp circuit. The ammeter or current circuit of the wattmeter should have a resistance such that the drop across it is less than 2 per cent of the lamp voltage. The voltmeter or voltage circuit of the wattmeter should have as high a resistance as possible with reliability; this should be at least 1,000 ohms per volt. The phase angle correction is negligible when only one instrument is connected in the lamp circuit. Correction or compensation for the voltage drop in any series elements of meters should be made unless they are less than $\frac{1}{2}$ per cent of lamp volts.

With a lamp in the circuit and with S_1 open and S_2 closed the corrections for the current in the voltmeter or power loss in the wattmeter can be determined. With S_1 closed and S_2 open the lamp is started and operated for about 10 minutes to allow conditions to become nearly constant before any measurements are made. A refinement of method is to place a foot-candle meter against the lamp or place the lamp on a photometer and

determine the light reading with no electric meters in the circuit and to adjust the line voltage to re-establish this reading when any meter is connected in the lamp circuit.

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SECTION 6

LIGHT SOURCES

It is known that man made use of the incandescent flame as a source of light even before the beginning of recorded history, and that more than half of the world's inhabitants and 10 per cent of American families use flame sources exclusively even today. The present efficiencies of the candle (0.1 lumen per watt), the kerosene lantern wick (0.3 lumen per watt), the acetylene flame (0.7 lumen per watt), and the illuminating gas flame have not changed greatly since they were first utilized for lighting purposes.

The first electric arc was discovered by Davy in 1801. Edison's first successful incandescent lamp in 1879 emitted 2.6 lumens per watt. In 1901 Cooper Hewitt's forerunner of modern gaseous discharge sources produced 13 lumens per watt. Thus by the time the Illuminating Engineering Society was founded in 1906 a recognizable ancestor of each of our present-day sources, with the possible exception of the fluorescent lamp, had already been developed.* See Fig. 6-1.

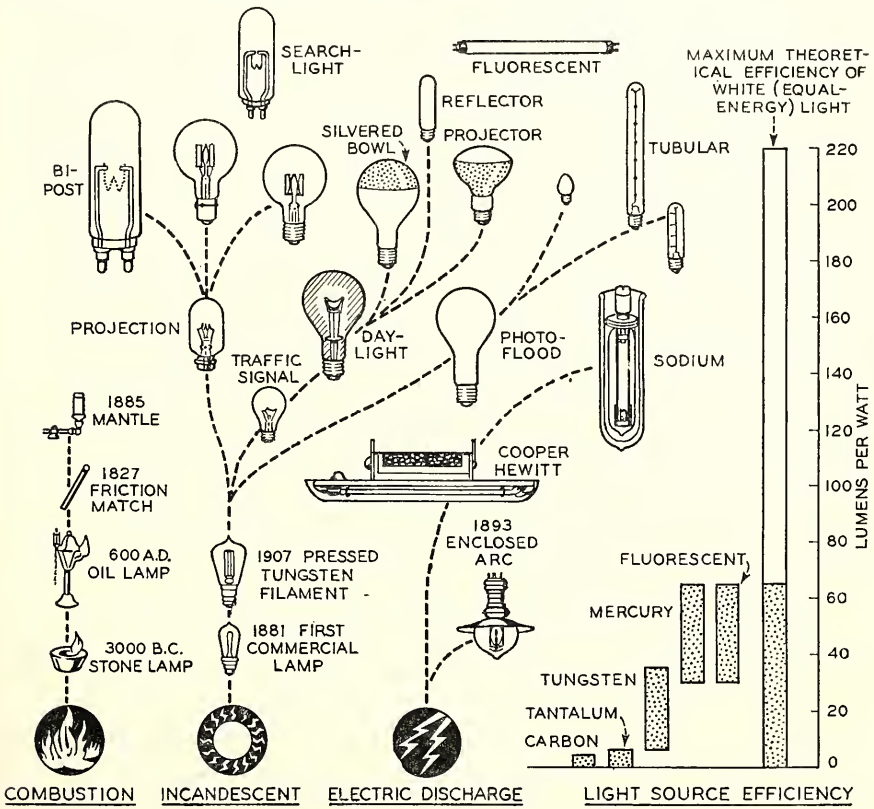


FIG. 6-1. A pictorial history of light source development and efficiency.

* In 1898 Edison applied for a patent on a "Fluorescent Electric Lamp" which was issued to him in 1907 as U. S. Patent No. F65,367.

References are listed at the end of each section.

Lamp Life and Depreciation

Rated lamp life is based on averages obtained from laboratory life-testing of large numbers of lamps. The normal "mortality" curve for incandescent lamps is shown in Fig. 6-2. Some lamps fail earlier than rated life, others last longer. A perfect mortality record would be one in which all lamps reached their rated life and then burned out. This is not to be expected in practice.

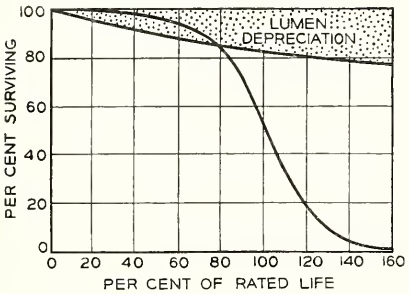


FIG. 6-2. Curve showing reduction in light output during life of a 200-watt general-service incandescent lamp superimposed on a typical incandescent-lamp mortality curve.

The depreciation curve superimposed on the normal mortality curve indicates that lamps which live substantially beyond rated life have become relatively inefficient. From an economic standpoint they should, under many circumstances, be replaced before burnout. From the normal mortality curve it will be seen that at the end of rated life 55 per cent of the lamps remain burning, but those remaining lamps will deliver only 6 to 8 per cent additional lumen-hours. These additional lumen-hours are the most expensive because they are being obtained at decreased efficiency. It is economical to remove lamps from service whenever the point is reached at which the cost of energy consumed per million lumen-hours exceeds the average cost of light produced up to that time, including all charges for lamps, energy, labor, and so forth. The point beyond which it is not economical to burn old lamps is termed the "smashing point. (See Fig. 6-3). The area under this curve represents the total lumen-hours produced by an assumed installation of lambs. It is obtained by combining the mortality curve with the typical depreciation rate throughout life. The darker-shaded part indicates the logical smashing point region where for the particular set of conditions assumed it is more economical to install new lamps than to keep the old ones in service. The light-shaded area represents the zone of group replacement, that is, of relamping the entire installation at one time before the normal rate of burnout reaches its peak.[1]

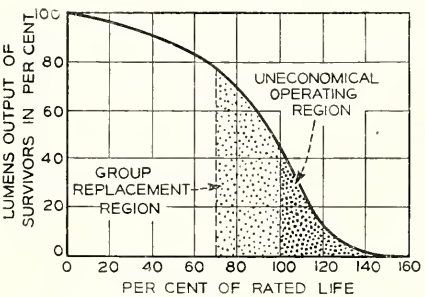


FIG. 6-3. Typical "smashing-point" curve obtained by combining a normal mortality curve with a typical depreciation-throughout-life curve.

Lamp Renewal Rate

From the mortality curve the number of burnouts likely to occur within a given period can be computed for a large installation. In a new installation few burnouts would be expected during the first several hundred hours. Approaching normal life, there would be many burnouts, necessitating frequent lamp replacement. Thus for a period of several lamp renewals per socket, the renewal rate first swings high, then low, and finally settles down to a steady rate, as in Fig. 6-4. The solid line represents the total replacements; the dotted curves the first, second, and so on replacement per socket. This theoretical curve holds only for an infinitely large installation. In practical installations the curve, because of the law of probability, is likely to be rather jagged, although the general shape would be the same.[2]

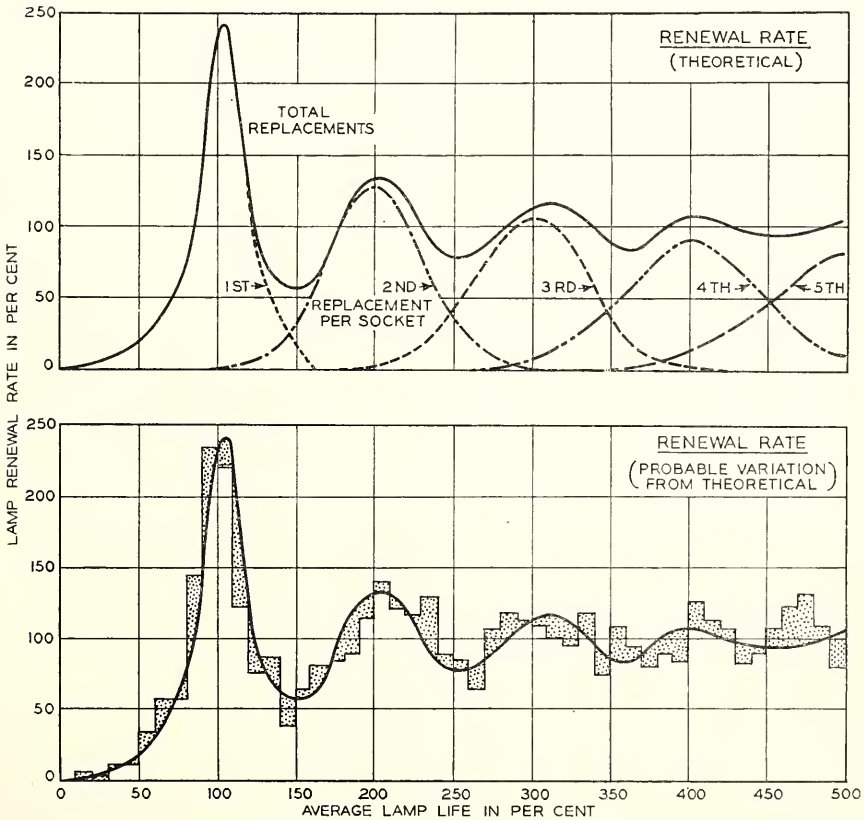


FIG. 6-4. Renewal rate curves applicable to all types of lamps.

THE INCANDESCENT LAMP

The first consideration of lamp design is that a source produce light most economically for the service intended, or, in other words, that the best balance of over-all lighting cost in terms of lighting results is secured. To realize this objective in an incandescent lamp the following factors must be definitely specified: filament material, length, diameter, form, coil spacing, mandrel size (the mandrel is the form on which the filament is wound), lead-in wires, number of filament supports, method of mounting, proper vacuum or filling gas, gas pressure, bulb size, bulb shape, temperature, and surface treatment (frosting, coating, silver or aluminum processing). (See Fig. 6-5.) Very careful production control is equally

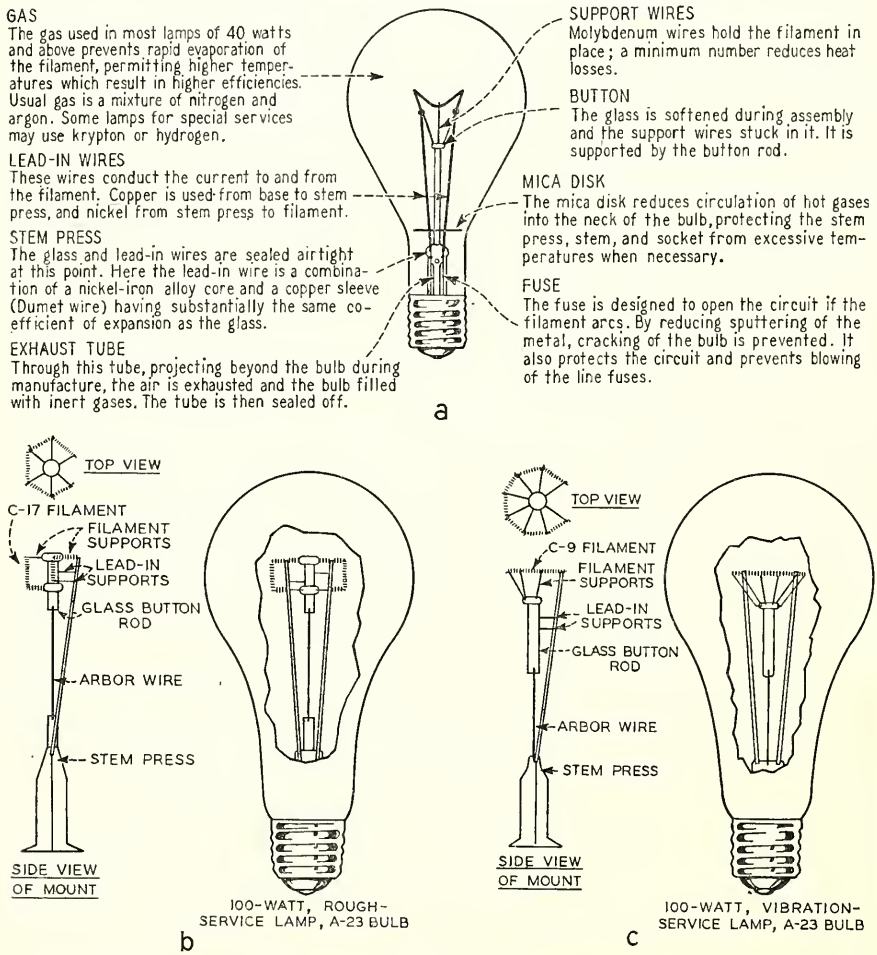


FIG. 6-5. Construction of common types of incandescent lamps for: (a) general service; (b) rough service; (c) vibration service.

necessary to ensure adherence to these specifications. Uniformity of wattage, efficiency, and life ratings is necessary if lamps are to give dependable service.[3] Typical filament forms are shown in Fig. 6-6.

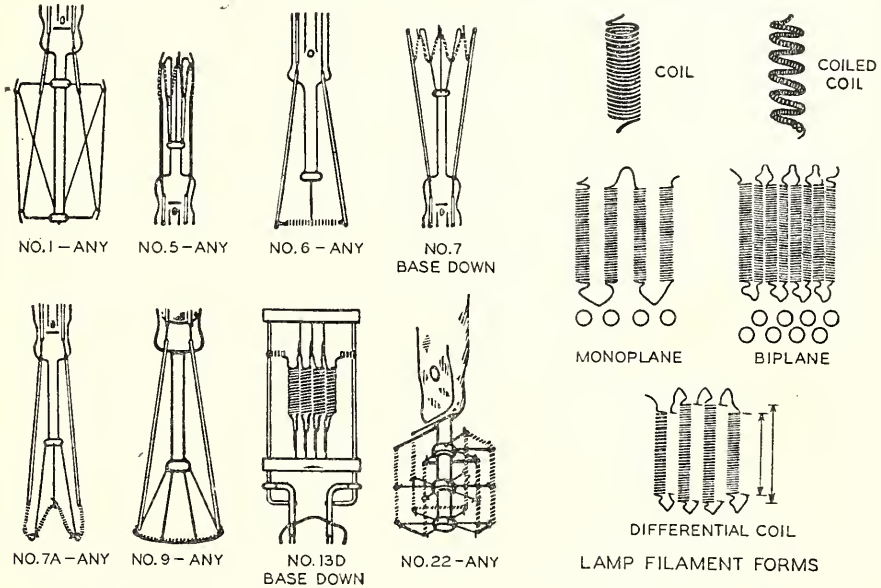


FIG. 6-6. Typical incandescent filament types, designations, and usual burning positions.

The Tungsten Filament

The requirements for a suitable material for a lamp filament involve the following:

Melting point and vapor pressure. Light output depends on filament temperature. An iron rod heated in a furnace will first glow a dull red, and then becomes brighter and whiter as its temperature is increased. Iron, however, melts at about 2,800 degrees Fahrenheit. Edison chose carbon as a filament because it has no melting point and vaporizes at 6,510 degrees Fahrenheit, which is above the melting point of tungsten (6,120 degrees Fahrenheit) and of any other known element. Carbon was the only filament material used for about twenty-five years.

To obtain satisfactory life performance, carbon lamps had to be operated much below the point of vaporization because of the high vapor pressure of carbon and the consequent high rate of filament evaporation at incandescent temperatures. Osmium (melting point 4,890 degrees Fahrenheit) and tantalum (melting point 5,250 degrees Fahrenheit), even though having melting points below the vaporization point of carbon, can be operated at higher temperatures for the same life since their vapor pressures and evaporation rates are lower. For a short period prior to the development of the tungsten lamp these metals were used as filament materials. Tungsten, first used in 1907 for lamp filaments, proved superior to all others because of its relatively high melting point and low

evaporation rate. Gas-filled lamps were introduced[4] in 1913, gas pressure being a practical means of retarding filament evaporation.

Strength and ductility. Early tungsten lamp filaments (1907–1911) were pressed from metallic tungsten powder and were very fragile. They were acceptable commercially only because their lumen-per-watt rating was approximately three times that of the relatively rugged carbon filaments then in use. In 1910 a method was developed for making ductile or drawn tungsten wire having four times the tensile strength of steel.[5]

Radiation characteristics. Tungsten selectively radiates a relatively high percentage of energy in the visible region, producing a continuous spectrum approximating that of a theoretical "blackbody."

The resistance of tungsten wire increases with its temperature, being of the order of twelve to sixteen times greater at filament operating temperatures than at room temperature as shown in Fig. 6-7. Theoretically,

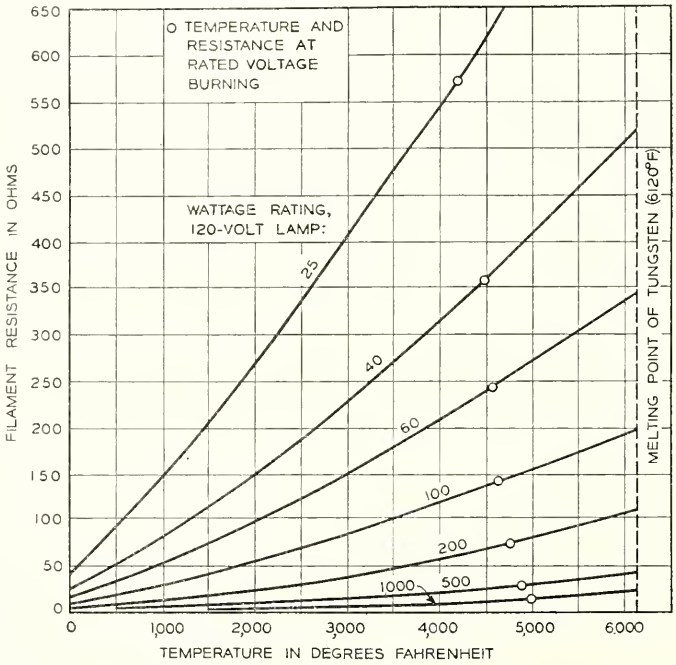


FIG. 6-7. Variation of tungsten filament resistance with temperature for various lamps.

then, an overshooting of current, in terms of normal current, would be expected at the instant lamps are turned on, in proportion to the ratio of hot-to-cold resistance. However, the reactance characteristics of the circuit rarely, if ever, allow this ratio to be reached. Table 6-1 gives the ratio of theoretical to actual current inrush as determined under laboratory conditions for several sizes of lamps. This aspect of lamp operation is important in the design and adjustment of circuit breakers, in circuit fusing, and in the design of lighting circuit switch contacts.

Table 6-1. Effect of Hot-Cold Resistance on Current in an Incandescent Filament

(Laboratory conditions)

LAMP WATTAGE	120-VOLT NORMAL CURRENT (amperes)	THEORETICAL INRUSH: BASIS HOT-TO-COLD RESISTANCE (amperes)	ACTUAL MAX. CURRENT INRUSH BY TEST (amperes)	TIME FOR CURRENT TO	
				Reach Max. Value (seconds)	Fall to Normal Value (seconds)
75	0.625	9.38	7.2	0.0004	0.07
100	0.835	13.0	9.0	.0007	.10
200	1.67	26.2	17.2	.0008	.10
300	2.50	40.0	26.2	.0011	.13
500	4.17	67.9	45.7	.0014	.15
750	6.25	101.9	51.7	.0021	.17
1,000	8.33	142.4	65.2	.0031	.23

Vacuum and Gas-Filled Lamps

The vacuum type of lamp was the only type available until 1913 and vacuum construction is still employed in 110- to 125-volt lamps consuming less than 40 watts. Lamps of 40 watts and above in the 110–125 volt range are usually gas filled.*

The bulb of an incandescent lamp is filled with gas to introduce pressure on the filament in order to retard evaporation. While the gas conducts some heat away from the filament, this is more than offset by the higher temperatures at which the filament may be operated.

Inert gases, that is, those that do not combine chemically with the filament lead-in wires and supports, must be used, and, other things being equal, the best gas is the one with lowest heat conductivity. Nitrogen was first used because of its lower cost, purity, and availability; argon was recognized as better than nitrogen in many ways but it was scarce and relatively expensive. Present-day lamps have an atmosphere of argon and nitrogen mixed in varying proportions depending on their type. Argon alone ionizes at normal circuit voltages and tends to arc between the lamp lead-in wires.

The rate of evaporation of a metal when surrounded by a gas varies with the size of the molecule of the gas. Krypton gas has a lower heat conductivity than either nitrogen or argon and if used for lamps would permit a 20 to 25 per cent gain in efficiency over the present 40-watt lamp rating. This gain would be less for the higher wattage lamps. However, krypton is at present too expensive to be used for all general-service lamps since its use would increase the present cost of the lamp perhaps by a factor of two. Its use is practical today only in special types of lamps such as the small miner's cap lamps, where high efficiency has a high money value since it prevents excessive drain on the battery, permits the use of smaller bulbs, and reduces the over-all weight of apparatus required to produce a given number of lumen-hours.

* Vacuum lamps are known as type B. Gas-filled lamps are known as type C.

Hydrogen has high heat-conductivity and is therefore inefficient for lamps for most purposes. However, this characteristic is useful in lamps used for signaling purposes where quick flashing (cooling) is desired. (See Fig. 6-8.)

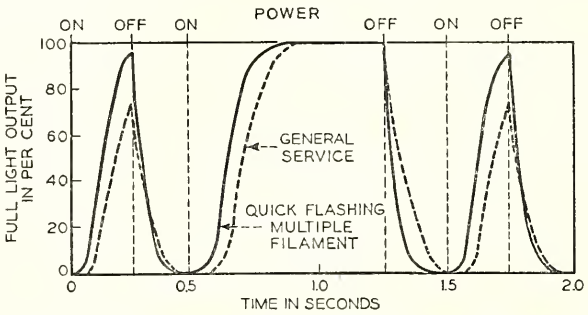


FIG. 6-8. Incandescence and nigrescence characteristics of "quick flashing" and general service lamps.

Table 6-2 shows thermal and luminous characteristics of several vacuum and gas-filled lamps. The filament dissipates its energy by radiation beyond the bulb, by conduction and convection of the surrounding gas, by conduction of the leads and supports, and by bulb absorption. By reference to the "Gas Loss" column of the table it will be noted that the percentage of gas loss increases rapidly as the wattage is decreased, the value for the 40-watt lamp being 20 per cent as compared with 6 per cent for the 1,000-watt lamp.

In manufacturing lamps, gas usually is introduced at about 70 to 80 per cent of atmospheric pressure. Operated under normal conditions the pressure rises to about atmospheric pressure. A lamp operated at more than normal temperatures may develop higher than atmospheric pressure within the bulb. When a hard glass bulb is used or when a bulb may be cooled by artificial ventilation, such as in projector housings, the filament temperature (and thereby the efficiency) may be increased. When this is done, it is advantageous to increase the internal gas pressure in order to minimize the vaporization of the filament. See Fig. 6-9.

Incandescent Lamp Life, Light Output, Efficiency, and Voltage Relationships

Operating data on twenty-two typical incandescent lamps are given in Table 6-3. An incandescent lamp of any given wattage and voltage rating may be designed to last a few hours or a few thousand hours. Lamps are available with life ratings throughout this range. For equal inherent quality, the shortest-life lamps of any given size and type have the highest lumen-per-watt ratings and the longest life lamps have the lowest lumen-per-watt ratings. For example, a photoflood lamp with rated life of six hours produces approximately 30 lumens per watt whereas lamps with a laboratory life of about 5,000 hours produce about 8 lumens per watt.

Table 6-2. Luminous and Thermal Characteristics of Typical Vacuum and Gas-Filled Incandescent Lamps

WATTS	RADIATED IN VISIBLE SPECTRUM (per cent of input wattage)	TOTAL FILAMENT RADIATION BEYOND BULB (per cent of input wattage)	GAS LOSS (per cent of input wattage)	END LOSS (Loss by conduction at Filament Ends) (per cent of input wattage)	FILAMENT HEAT CONTENT (joules)	HEATING TIME TO 90 PER CENT LUMENS (seconds)	COOLING TIME TO 10 PER CENT LUMENS (seconds)	STROBOSCOPIC EFFECT (Per cent of variation of light output from mean)	
								60 Cycles	25 Cycles
6*	6.0	93.0	—	1.5	0.25	0.04	0.01	29	69
10*	7.1	93.5	—	1.5	0.62	.06	.02	17	40
25*	8.7	94.0	—	1.5	2.8	.10	.03	10	28
40†	7.0	69.9	20.0	1.6	2.5	.07	.03	13	29
60†‡	7.5	80.8	13.5	1.2	5.5	.10	.04	8	19
100†‡	10.0	82.0	11.5	1.3	14.1	.13	.06	5	14
200†	10.2	77.4	13.7	1.7	39.5	.22	.09	4	11
300†	11.1	79.8	11.6	1.8	80.0	.27	.13	3	8
500†	12.0	82.3	8.8	1.8	182.0	.38	.19	2	6
10000†	12.1	87.4	6.0	1.9	568.0	.67	.30	1	4

* Vacuum. † Gas filled. ‡ Coiled-coil filament.

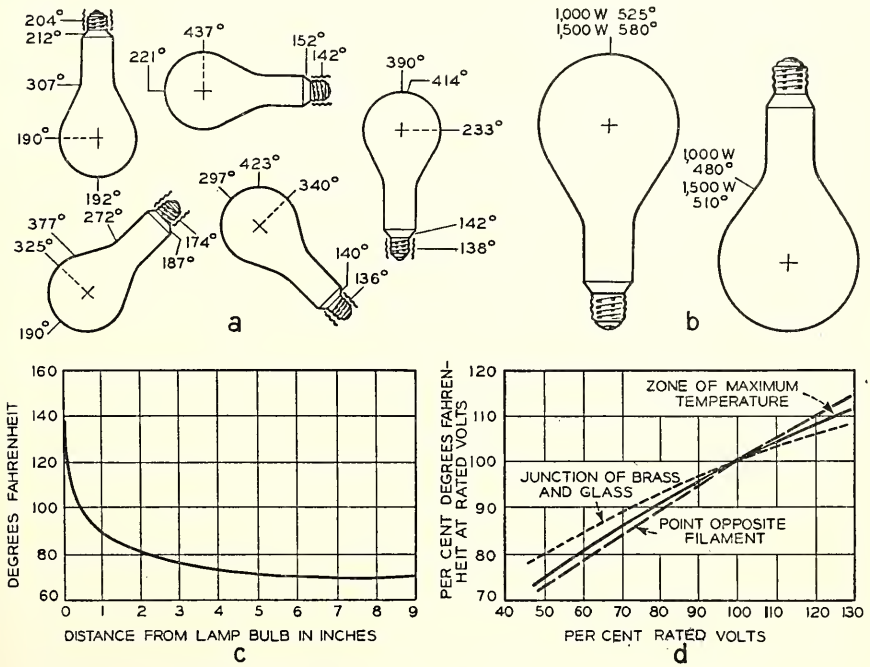


FIG. 6-9. Incandescent lamp operating temperatures: (a) 200-watt lamp; (b) 1,000- and 1,500-watt lamps in PS-52 bulbs; (c) temperature gradient in air surroundings a 100 watt lamp; (d) effect of voltage on temperature.

The following equations enable the lamp user and designer to predetermine the performance under varying conditions of either gas-filled or vacuum lamps (capital letters represent normal rated values):

$$\frac{\text{life}}{\text{LIFE}} = \left(\frac{\text{LUMENS}}{\text{lumens}}\right)^{a} = \left(\frac{\text{LUMENS/WATT}}{\text{lumens/watt}}\right)^{b} = \left(\frac{\text{VOLTS}}{\text{volts}}\right)^{d} = \left(\frac{\text{AMPS}}{\text{amps}}\right)^{u}$$

$$\frac{\text{lumens}}{\text{LUMENS}} = \left(\frac{\text{volts}}{\text{VOLTS}}\right)^{k} = \left(\frac{\text{lumens/watt}}{\text{LUMENS/WATT}}\right)^{h} = \left(\frac{\text{watts}}{\text{WATTS}}\right)^{s} = \left(\frac{\text{amps}}{\text{AMPS}}\right)^{y} = \left(\frac{\text{ohms}}{\text{OHMS}}\right)^{z}$$

$$\frac{\text{LUMENS/WATT}}{\text{lumens/watt}} = \left(\frac{\text{LUMENS}}{\text{lumens}}\right)^{f} = \left(\frac{\text{VOLTS}}{\text{volts}}\right)^{g} = \left(\frac{\text{AMPS}}{\text{amps}}\right)^{j}$$

$$\frac{\text{amps}}{\text{AMPS}} = \left(\frac{\text{volts}}{\text{VOLTS}}\right)^{t} \text{ and } \frac{\text{watts}}{\text{WATTS}} = \left(\frac{\text{volts}}{\text{VOLTS}}\right)^{n}$$

Table 6-3. Performance Data on Standard Incandescent Lamps

WATTS	BULB‡ (Clear or frosted)	VOLTS	AMPERES	APPROX. INITIAL ‖LUMENS	RATED INITIAL LUMENS PER WATT	RATED AVERAGE LIFE (hours)§	UNCOILED FILAMENT LENGTH (inches)	FILAMENT WIRE‖ (diameter in inches)	FILAMENT TEMPERATURE (F)	MAXIMUM BARE BULB TEMPERATURE¶ (F)	BASE TEMPERATURE (F)
6	S-14	120	0.050	40	6.6	1,500	14.4	0.00047	3,860	93	88
10	S-14	120	0.083	80	8.0	1,500	17.0	.00065	3,900	106	106
25	A-19	120	0.21	260	10.4	1,000	21.9	.0012	4,190	110	108
40	A-19	120	0.34	465	11.7	1,000	15.0	.0013	4,490	260	221
60*	A-19	120	0.50	835	13.9	1,000	20.8	.0018	4,530	252	195
100*	A-21	120	0.83	1,630	16.3	750	22.6	.0025	4,670	261	201
100	A-23	240	0.42	1,240	12.4	1,000	35.7	.0016	4,470	285	228
100	A-23	30	3.12	1,850	18.5	1,000	8.2	.0062	4,660	285	228
100 (proj.)	T-8	120	0.83	1,920	19.2	50	19.4	.0025	4,890	—	—
150	PS-25	120	1.25	2,600	17.2	750	25.0	.0032	4,710	290	209
200	PS-30	120	1.67	3,650	18.3	750	25.2	.0038	4,750	307	212
300	PS-35	120	2.50	5,900	19.7	750	27.6	.0050	4,825	374	173
500	PS-40	120	4.17	10,000	20.0	1,000	31.6	.0071	4,840	389	213
1,000	PS-52	120	8.3	21,500	21.5	1,000	39.5	.0111	4,930	475	235
1,000	PS-52	240	4.2	19,100	19.1	1,000	68.3	.0073	4,760	475	235
1,000 (proj.)	T-20	120	8.3	28,000	28.5	50	33.4	.0110	5,590	—	—
1,000 (spot)†	G-40	120	8.3	22,500	22.5	200	38.3	.0114	5,200	756	192
1,500	PS-52	120	12.5	33,000	22.0	1,000	43.5	.014	5,010	505	265
2,000	PS-52	120	16.7	44,000	22.0	1,000	46.2	.018	5,030	855	—
3,000	T-32	32	93.8	88,500	29.5	100	13.6	.048	5,390	—	—
5,000	G-64	120	41.7	164,000	32.7	75	44.4	.029	5,360	860	—
10,000	G-96	120	83.4	325,000	32.7	75	54.5	.046	5,540	—	—

* Coiled-coil filament. † Vertical base down. ‡ See Fig. 6-11. § Under specified laboratory test conditions. ‖The practice is to weigh a length of 20-mm wire and calculate the diameter. ¶ At an ambient temperature of 77 degrees Fahrenheit the maximum bare bulb temperature is measured with the lamp operating vertically base up; the base temperature is measured at the junction of the base and bulb. (See also Fig. 6-9.)

The exponents are as follows:

	a	*b*	*d*	*u*	*h*	*k*	*s*	*y*
Gas-filled lamps	3.86	7.1	13.1	24.1	1.84	3.38	2.19	6.25
Vacuum lamps	3.85	7.0	13.5	23.3	1.82	3.51	2.22	6.05

	z	*t*	*n*	*f*	*g*	*j*
Gas-filled lamps	7.36	0.541	1.54	0.544	1.84	3.40
Vacuum lamps	8.36	0.580	1.58	0.550	1.93	3.33

Exponents d, k, and t are taken as fundamental. The other exponents are derived from them. Values given apply to lamps operated at efficiencies near normal and are accurate enough for calculations in the voltage range normally encountered.[6]

The curves in Fig. 6-10 show the effects of operating an incandescent lamp at other than its rated voltage. These characteristics are averages for many lamps of the gas-filled type and are slightly different from those of vacuum types.

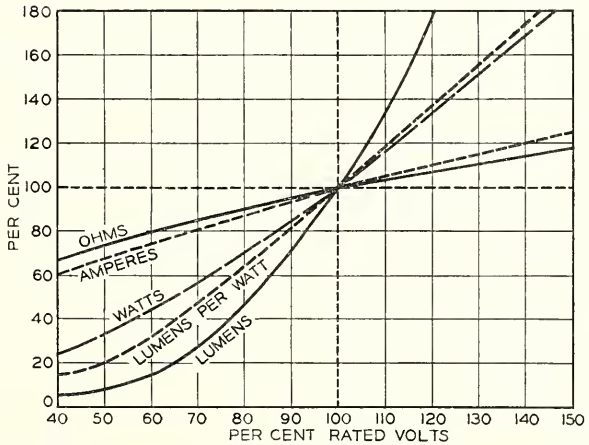


FIG. 6-10. Effect of voltage variation on operating characteristics of incandescent lamps.

Neither the theoretical life of lamps calculated by the exponential relationship of life and voltage nor the rated laboratory life is exactly realized in practical installations since handling, cleaning, vibration, and under- or overvoltage operation introduce factors which are not considered in the calculated or laboratory ratings.

Incandescent Lamp Depreciation and Bulb Blackening

Multiple lamps depreciate in light output throughout life partly as the result of gradual filament evaporation as the lamp is burning; this depreciation is a normal and inevitable result of operation. As the filament evaporates it becomes thinner and its resistance increases and the current, wattage, and lumen output all decrease, but not in the same ratio. Figure 6-2 shows the depreciation in the light output characteristic of a 200-watt, general-service lamp. Depreciation curves for other wattage and bulb sizes (excepting the silver-processed) will show the same trend.

The light output of a series lamp operated at rated constant current changes relatively little during life. The filament, evaporating and becoming smaller as the lamp is burned, gradually increases in resistance, requiring a rise in voltage to maintain a constant current value. This in turn increases the wattage and filament temperature, causing an increase both in efficiency and in the lumens produced by the filament. The increased lumens from the filament may eventually be offset by the light that is absorbed as the bulb blackens. The light output of the 15-ampere and 20-ampere compensator (series) lamps may drop below the initial value early in life and continue to decrease throughout life. Net changes in lumen output will vary little with bulb size, shape, and burning position.

In vacuum lamps the blackening resulting from the tungsten particles is spread over the inner bulb surface. In gas-filled lamps the hot gas stream carries the particles upward and causes a relatively dark spot to appear above the filament. When lamps are burned base up, part of the blackening will be deposited on the neck area where much of the light is normally intercepted by the base. Thus the lumen maintenance of a lamp operated base up will be better than for base-down operation.

To reduce blackening and to perfect the inner atmosphere, an active agent known as a "getter" is used inside the bulb. The chemicals making up the getter can be solids applied to the filament or leads or gasses.

In certain lamps in which blackening would not be reduced enough by getters alone, various other means are also employed. Some of the high-wattage lamps used in motion picture photography have a small amount of loose tungsten powder in the bulb, which, when shaken about, wipes off much of the blackening. The general-service, bipost-base lamps have a "collector grid" (a wire mesh screen) located above the filament. This screen reduces blackening by attracting and condensing the tungsten vapor and holding the tungsten particles.

Lamp Voltage Classes

Standard general lighting lamp voltages are 115, 120, and 125 volts. Lamps generally available in any community should conform to the nominal voltage of the distribution system serving the territory. Recent country-wide surveys of voltages indicated 1.3 per cent of the population served at 110 volts, 43.4 per cent at 115 volts, 55.3 per cent at 120 volts, and 0.1 per cent at all other voltages in the 110–130 volt range. Lamp purchases by voltage do not coincide with these proportions, rather they show that a larger proportion of lamps of higher voltage rating are being used than service voltages call for.

High-voltage lamps necessarily have filaments of smaller diameter and greater length. The filaments are less rugged, require more supports, and are less efficient than those of equal wattage 120-volt lamps. A 240-volt lamp will take but half the current of the same wattage 120-volt lamp, permitting some economy in the wiring of lighting circuits.[7]

Low-voltage lamps (6- to 64-volt circuits). Lamps are designed for the several classes of low-voltage service generally provided by battery-generator systems. For train lighting, lamps are rated 30, 32, 60, and 64 volts. The 30-volt lamps are also known as "Country Home Lamps" because they are used most often in individual farm-lighting systems.

Battery-generator systems also supply lighting for automobiles, trailers, boats, and airplanes, for isolated beacons and aviation landing fields, and for many similar places where central station service is usually not available. Except that these lamps have conventional large bulbs and bases they might be classed as miniature lamps; there is no sharp dividing line between the so-called large and miniature lamp classifications. Generally speaking, lamps designed for operation on circuits of less than 30 volts are considered miniature lamps, and have small bases.

Low-voltage lamps, because they utilize a shorter and heavier filament for a given wattage, are more rugged and, in general, more efficient than lamps of the 120-volt class.[8]

Street-railway lamps (525- to 625-volt circuits). Street-railway service requires lamps designed for that application. Circuit voltages (including shop and yard circuits) range from 525 to 625 volts. Some lamps are designed to operate 5-in-series on these voltages. Dividing the trolley voltage by 5 gives the design voltage of the individual lamp. The high circuit voltage and the fact that these lamps are connected in series dictates specially designed lamps for this service. To identify them, lamps for street railway service are rated in odd wattages (36, 56, 94, 101, and so forth) to distinguish them from multiple burning lamps. The larger, gas-filled lamps, identified by the numeral 1 as the last digit, are designed and constructed to prevent arcing when burnout occurs.

The number of 30-volt lamps on a street-railway circuit is determined by dividing the trolley voltage by 30. Each lamp is equipped with an automatic short-circuiting element which shunts the lamp out of the circuit when the lamp burns out. These lamps are rated in amperes instead of watts. Lamps rated 1.0 and 1.6 amperes are available.

Street series lamps. Street series lamps are designed to operate in series on constant current circuits. The most common circuit carries 6.6 amperes and is automatically regulated to maintain this current flow regardless of the number of lamps used on the circuit. Lamps are designed also for 5.5-, 7.5-, 15-, and 20-ampere operation, the higher currents usually being obtained for each lamp by an individual step-up current transformer connected to a normal series circuit. These are known as compensator lamps.

Lamps are designated by their rated initial lumen output and ampere rating, for example, the 6,000-lumen, 6.6-ampere lamp, or the 25,000-lumen, 20-ampere lamp. Though series lamps as small in output as 250 lumens are available, the standard sizes range from 1,000 to 25,000 lumens. Wattage and voltage ratings, as used to designate multiple lamps, are not commonly employed. Multiple lamps are designed for a definite wattage at a definite voltage and changes in efficiency are shown by

changes in lumen output; the lumen output of series lamps, on the other hand, remains fixed because generally the lumen output is specified in street lighting contracts, and changes in efficiency resulting from improvements are reflected by changes in wattage or voltage. This usually results in odd numbers and fractions, for example, the present 6,000 lumen, 6.6-ampere lamp has an average rating of 46.9 volts and 310 watts.

On a constant current circuit the filaments for all sizes of lamps of a given current rating are of approximately the same diameter but vary in length according to the lumen output. The lamp voltage will vary with the lumen output, ranging from a few volts in the smaller sizes to 50 or 60 volts for the lamps of high lumen rating.

Series circuits should be closely regulated as fluctuations from normal current will cause considerable variation in lamp performance. The effect of current variation in series operation is considerably greater than that of voltage variation on multiple operation. Roughly a 1 per cent change in amperes (0.066 ampere on a 6.6-ampere circuit) will produce a change of about $1\frac{1}{2}$ per cent in volts, about $2\frac{3}{4}$ per cent change in watts, about $3\frac{1}{2}$ per cent change in efficiency, about 7 per cent change in light output and about 20 per cent change in life.

The increase in voltage and wattage of lamps on series circuits will amount to about 4 per cent above the initial rating at the end of their rated life, averaging about 2 per cent during life. Provision should be made in the capacity of constant current transformers for this increase in voltage.

Bulb Shapes and Finishes

Shapes of common incandescent lamp bulbs are shown in Fig. 6-11. For general lighting there is almost complete standardization of lamps in the A and PS bulb shapes. Lamps rated 15–100 watts are frosted inside. Lamps in the 150–1,500 watt range may be either clear or frosted. Flame-shaped and round-bulb lamps are available in 15-, 25-, and 40-watt sizes for ornamental fixtures where the bulbs are exposed and where the bulb shape is related to the artistic design of the luminaire.

Tubular bulb lamps extend lighting applications since they can be placed in small inconspicuous reflectors for display cases, small coves, and narrow cavities. Intermediate and medium screw bases are used on these sources. Projection lamps employ tubular bulbs because of space limitations; prefocused bases are most common. The Lumiline lamp represents a considerable departure from conventional lamp construction since the filament extends between the contact caps at the ends. Special disk bases and lamp holders are employed. The lumen output of tubular bulb lamps is reduced below that of globe-shaped lamps of the same wattage rating because the additional supports required cause a heat loss.

Many types of lamps are available with bulbs made of "hard" or "heat-resisting" glass. Such bulbs withstand higher temperatures than ordinary lead or lime glass, and are used on most lamps of the spotlight, flood-

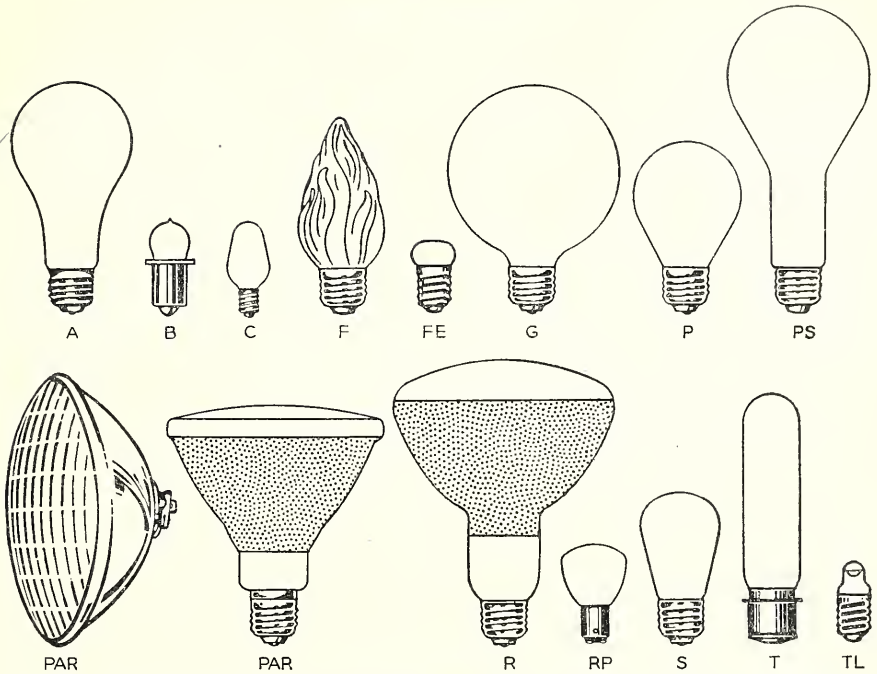


FIG. 6-11. Shapes of common incandescent lamp bulbs. In bulb-type designations the letters indicate shape; numerals following the letters indicate the nominal diameter in eighths of an inch.

light, and projection types and for general applications where high-wattage lamps are exposed to rain or snow.

Bulb finishes and colors. Inside frosting is widely applied to many types and sizes of bulbs. Frosting gives moderate diffusion of the light, thus reducing the extremely high filament brightness when lamps are used exposed, and eliminating striations and shadows when used in most types of equipment. By frosting inside the bulb, the outer bulb surface is left smooth and easily cleaned; furthermore, the light absorbed by the inside frosting is scarcely measurable. Though white glass or white-coated bulbs give greater diffusion, the loss of light is of the order of 15 per cent.

White bowl lamps have a white diffusing coating on the inside of the bowl and are applicable principally in open direct-lighting reflectors. This coating redirects about 80 per cent of the incident light upward, 20 per cent being transmitted diffusely through the bowl. Thus the bulb brightness of these lamps is considerably lower than that of the clear bulb type of the same wattage.

Daylight lamps have blue-green glass bulbs which absorb some of the red and yellow wavelengths. They therefore have a higher color temperature and appear whiter. The color correction accomplished at the expense of about 35 per cent reduction in light output through absorption falls about midway between unmodified tungsten-filament light and standard natural

daylight. The color temperature of daylight lamps varies between 3,500 to 4,000 degrees Kelvin.[9]

Colored lamps in diffusing bulbs are available in three different types of finishes: (1) outside spray-coated, (2) inside-coated or enameled, and (3) ceramic glazed glass. Outside-coated lamps are suitable for indoor use where not exposed to the weather. Their surfaces collect dirt readily and are not easily cleaned. Inside-coated or enameled bulbs have smooth outside surfaces that are easily cleaned. The pigments are not subjected to weather and therefore have the advantage in permanence of color. Ceramic glazed finish is a recent development which gives a permanent finish to the bulb with the ceramic pigments fused into the glass but some colors are not as uniform and the efficiency attainable is approximately 20 per cent lower than equivalent lamps of clear or natural-colored glass.

Natural-colored-glass lamps are used where permanence of color is desired. These lamps cost somewhat more than coated lamps but because of their greater efficiency of light transmission, the over-all cost of producing colored light with natural colored lamps is about the same as with coated lamps. Only a few colors (ruby, blue, green, and amber) are regularly available.

Reflector-Type Lamps

This general designation refers to lamps in which light control is built into the lamp itself by applying either silver or aluminum to the outside or the inside surface of the bulb. Not only has a reflecting surface been applied to common bulb shapes but also quite a number of bulbs have been developed in which bulb contour and reflecting surfaces are coordinated to provide specific distributions of light. The most extensive use of specialized bulb contours has been in the sealed beam headlamps found in 1940 and later automobiles.

Silvered-bowl lamp. The silvered bowl lamp represents the most common reflector lamp for general lighting applications. Such lamps are processed in two ways, with silvering applied either internally or externally. In the latter type of lamp a finish of pure silver is deposited on the bulb and sealed with an electrolytic coating of copper; over these two metallic coatings an aluminum or bronze finish is applied. The reflecting surface is thus protected from all dust, dirt, and deterioration.. The light control achieved is accompanied by an initial loss of only 6 to 10 per cent in light output.

This process has also been applied in neck silvering, and such lamps are being used to provide the specialized light distribution required for street lighting service, or for such general applications as high-bay and window lighting.[10]

Projector lamp. A wide variety of light beam patterns can be incorporated in a lamp by co-ordinating filament positioning with respect to special bulb reflecting contours. In the projector flood and projector spot lamps, designated as type PAR, the bulb is constructed of two molded glass sections. A bowl-shaped section of parabolic or other suitable con-

tour on which a highly efficient reflecting film of aluminum has been vaporized serves as the reflector. This section incorporates the base and filament. A molded glass cover plate, either clear or configurated in any desirable lens pattern, is then fused to the reflector section. Made of hard glass, this type of lamp may be used out of doors without danger of thermal cracks. Louvers, shields, and color filter fittings may be supported by the bulb.

Reflector lamp. The reflector lamp has a blown glass bulb of special reflector contour and an inside aluminized or silvered surface. This construction is less expensive than type PAR, used in projector lamps. It is suitable for interior spotlighting and floodlighting but the practice of spring fitting accessory shields and filters to these bulbs is not advisable because of the likelihood of thermal cracks and premature lamp failure.

Candlepower distribution curves for various sizes of projector and reflector lamps are shown in Fig. 6-12.

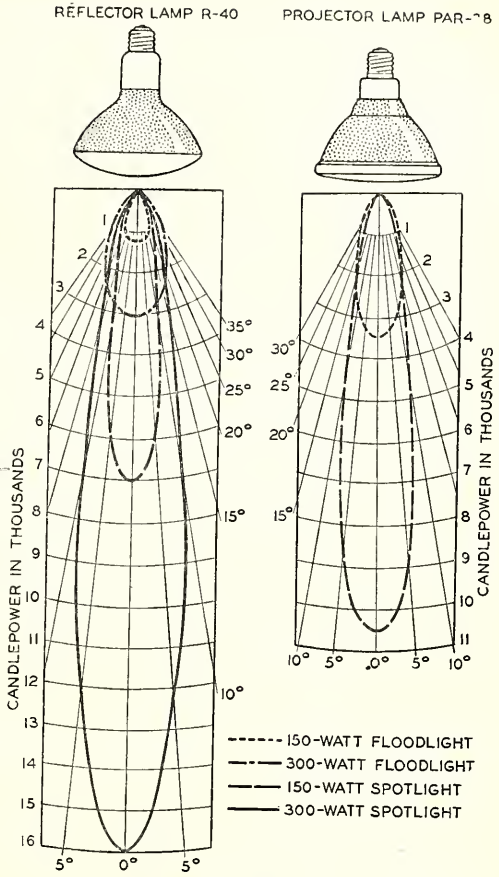


FIG. 6-12. Candlepower distribution characteristics of several reflector lamps.

Type L (sealed-beam) reflector lamps. In the sealed-beam headlight systems, fog lamps, spot lamps, tractor lamps, airplane landing lamps, signaling lamps, and so forth, one or two filaments are accurately mounted with respect to an aluminized glass reflector and this is then hermetically sealed to the cover lens. The lamp is gas-filled, the sealing tube sealed off, and the lamp based with special prong or screw terminals. Three advantages of this construction are:

1. The glass reflector section is of reasonably precise contour and is not subject to denting or springing out of shape during processing and handling. This results in good beam control.[11]

2. The short stocky filament supports are rugged and filaments are carefully positioned before the lens section is sealed on.

3. Aluminum vaporized on glass is one of the best reflectors, does not tarnish, and as a sealed-in reflecting surface is not subject to the deprecia-

tion from dust, dirt, and moisture, which succeed by "breathing action" in getting into all except the most perfectly gasketed enclosures.

Photographic and Projection Lamps

Photoflood, photoflash, and *photo-enlarger* lamps as well as *projection* and *photocell exciter* types are described in Section 14.[12, 13, 14, 15]

Other Incandescent Lamps for Specialized Service

Lamps made in very small quantities for specific applications are sometimes available even though not found in the standard lamps catalogues. Unless a very large number of lamps (more than 10,000, for instance) is desired, it is usually not feasible to develop a new design.

Spotlight and floodlight lamps. Lamps for this service have concentrated filaments, usually of type C-5, accurately positioned with respect to the base. When the filament is placed at the focal point of a reflector or lens system, a sharply controlled beam is obtained.

Photometric standard lamps. These lamps of both the vacuum and gas-filled type are available for use with comparison photometers, and are specially made to ensure stability and uniform performance.[16]

Bake-oven lamps. These sources have four special features not included in low-wattage, general-service lamps: (1) a special basing cement which will withstand temperatures up to 550 degrees Fahrenheit is used; (2) the lead wires are welded to the base; (3) an asbestos insulation is placed between the leads in the base so that falling oxide will not cause a short circuit; and (4) bake-oven lamps undergo a special high-temperature exhaust, giving improved operation and longer life at the high external temperature involved.

Rough-service lamps. The filaments (C-17 or C-22) of lamps designed to withstand shocks and bumps are coiled on a very small mandrel. This results in a relatively long coil which is carefully mounted and held by many supports (the 50-watt, 115-volt, rough-service lamp has sixteen supports). Because of the number of supports, the heat loss is higher and the efficiency lower. These lamps find their principal application in portable luminaires on extension cords in garages, industrial plants, and similar places. (See Fig. 6-5b.)

Vibration-service lamps. Most lamps have coiled filaments made of a specially prepared tungsten having high sag resistance. However, those vibration lamps designed for use where continuous high-frequency vibrations would cause early failure of general-service lamps, are made with a more flexible tungsten filament. The sagging characteristic of the wire used allows the coils to open up under vibration, thus preventing short circuits between coils.

Vibration and shock frequently accompany each other and sometimes only experiment will determine the best lamp for the purpose. Vibration-resisting adaptor socket mounts utilizing a coiled spring or other flexible material to deaden vibration have been employed where general-service lamps are used under conditions of severe vibration.[17] (See Fig. 6-5c.)

Miniature lamps. See Section 15.

Lumiline and showcase lamps. The Lumiline type has two disk bases, one at each end of the lamp, with the filament connected between them. The filament, in the form of a loose coil, is supported at intervals along the tube from a small metal channel next to the inside wall of the tube and insulated from the two contact ends. Thirty and 60-watt sizes are available in the 18-inch length, and the 40-watt is made in a 12-inch length. All sizes are available in either clear or inside-frosted tubes, or in various color coatings.

Showcase lamps have a conventional screw base. The longer lamps have elongated filaments with filament supports similar to Lumiline lamps. The common sizes are 25 and 40 watts, but sizes up to 150 watts are available.

Three-light lamps. These employ two filaments, operated separately or in multiple to provide three levels of illumination. The common filament lead-in wire is connected to the shell of the base; the other end of one filament is connected to a ring contact and the end of the other filament to a center contact.

Sign lamps. While large numbers of gas-filled lamps are used in enclosed and other types of electric signs, those designated particularly as "sign" lamps are mostly of the vacuum type. Lamps of this type are best adapted for exposed sign and festoon service because the lower bulb temperature of vacuum lamps minimizes thermal cracks resulting from rain and snow. Some low-wattage lamps, however, are gas-filled for use in flashing signs. Bulb temperatures of these low-wattage, gas-filled lamps are sufficiently low to permit exposed outdoor use. See Fig. 6-8.

Incandescent Lamp Bases

Types and dimensions of bases used on common incandescent lamps have been standardized rather completely. Figure 6-13 shows the common types of incandescent lamp bases.

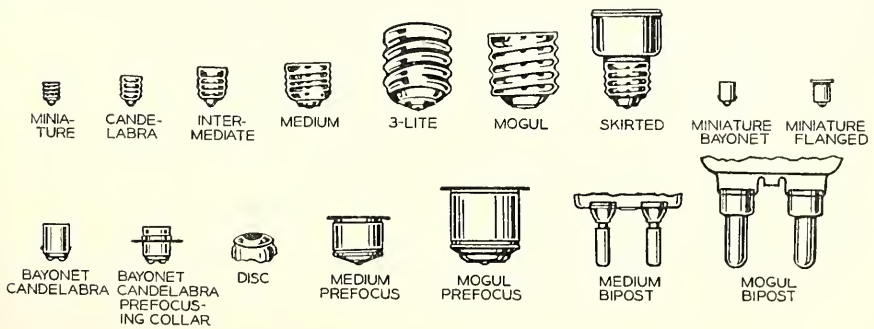
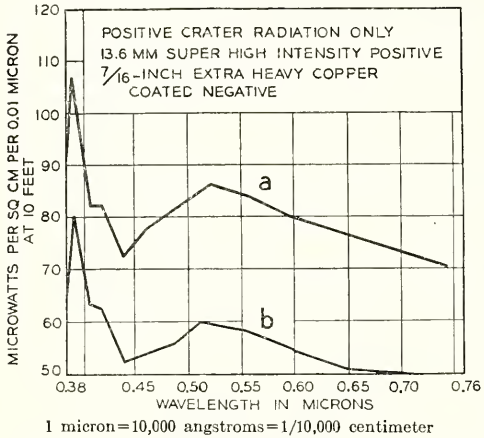


FIG. 6-13. Common incandescent lamp bases.

CARBON-ARC LAMPS

Arc sources, which were the first commercially practical electric light sources, now are used where an extremely high brightness "point" source is necessary, or where their radiant energy spectrum is advantageous.



1 micron=10,000 angstroms=1/10,000 centimeter

FIG. 6-14. Spectral distribution of radiant energy at a distance of 10 feet from a direct-current arc (high-intensity, motion-picture-projector carbons) operated at (a) 185 amperes, 75 volts; (b) 140 amperes, 60 volts.

Figure 6-14 shows the spectral energy distribution from a high-intensity, direct-current arc (motion picture projector carbons). Arcs may be operated either in the open air or within a glass or quartz enclosure.

Because of the negative volt-ampere characteristic of arcs, they must be operated on circuits including ballast resistances or reactances (either in the generating or rectifying equipment or as separate units in the arc circuit). In starting a carbon arc it is necessary to bring the two electrodes together instantaneously, after which they are separated to the proper distance to maintain the correct arc voltage and current. These conditions can be maintained and the carbon fed manually, but in most carbon arc lamps automatic mechanisms feed the carbons as they are consumed, and regulate the arc length and position of the light source.[13, 19]

The source of light in a carbon arc is the incandescent solid crater in the plain- or low-intensity arc, the incandescent vapors of the cerium rare-earths in the cup-shaped crater of the high-intensity arc, and the arc stream or "flame" in the flame arc, as shown in Fig. 1-10, page 1-15. Table 6-4 gives the color characteristics of various arcs in reference to average daylight and to sunlight. See Section 14 for applications.

ELECTRIC DISCHARGE LAMPS FOR LIGHTING APPLICATIONS

Mercury, sodium, and neon are the elements most widely used at present in discharge lamps because the temperature, pressure, voltage, and other related considerations necessary to produce light utilizing these elements are relatively easy and inexpensive to provide. Different metals may be used for electrodes. These are often coated with electron-emissive barium or strontium oxide. Electrodes emit electrons more readily when hot than when cold.[20]

Once started, discharge lamps may operate at less than line voltage; the heating effect of the arc keeps the electrodes hot regardless of starting temperature. The enclosed arc emits light at the instant when the discharge begins between one electrode acting as a cathode and the other acting as an anode. If connected to an alternating-current power supply, the electrodes exchange functions as the power supply changes polarity.

Table 6-4. Color Temperature of Carbon Arcs with Dominant Wavelength and Per Cent Purity Referred to Average Daylight (6,500 degrees Kelvin) and to Noon Sunlight (4,200 degrees Kelvin) at Springfield Lake, Ohio[19]

LIGHT SOURCE	AMPERES	VOLTS	COLOR TEMPERATURE (K)	DOMINANT WAVELENGTH (MICRONS) REFERRED TO		PURITY (PER CENT) REFERRED TO	
				Daylight	Sunlight	Daylight	Sunlight
11-mm high-intensity carbons	90	56.5	6,400	0.5640	0.4800	4	22
8-mm Suprex carbons	65	38.0	6,400	.5650	.4800	5	21
8-mm Suprex carbons	56	43.0	6,250	.5700	.4790	5	20
16-mm high-intensity carbons	150	81.0	6,000	.5740	.4780	7	18
7-mm Suprex carbons	50	36.0	5,950	.5710	.4800	9	19
½-inch x 12-inch rotary spot carbons	80	53.0	5,600	.5900	.4750	9	17
6-mm Suprex carbons	40	32.0	5,850	.5750	.4790	9	18
9-mm high-intensity carbons	70	49.0	5,800	.5760	.4780	9	17
7-mm Suprex carbons	42	33.0	5,800	.5740	.4790	10	17
13.6-mm super-high-intensity carbons	185	75.0	5,480	.5740	.4800	10	14
13.6-mm high-intensity carbons	125	63.0	5,650	.5730	.4800	12	16
6-mm Suprex carbons	30	28.0	5,250	.5770	.4780	16	13
8-mm motion-picture-studio carbons	40	37.5	4,650	.5780	.4750	25	6
12-mm low-intensity carbons	30	55.0	3,550	.5830	.6050	40	9

Because discharge lamps, like other arc sources, have an inherent negative resistance characteristic, suitable current ballast or control as well as starting equipment is necessary.

This current-limiting equipment (sometimes referred to as the "auxiliary") is necessary for the operation of every discharge lamp. It increases the total power consumed and, if not "power factor corrected," reduces the power factor of the circuit below that of the lamps. Power factor correction by capacitors is effective and frequently practiced.[21]

Mercury-Vapor Discharge Lamps

The mercury-vapor pressure at which a lamp operates accounts in a large measure for its characteristic spectral energy distribution. In general, higher operating pressure tends to shift a larger proportion of the emitted radiation into longer wavelengths. At extremely high pressures there is a tendency to spread the line spectrum into wider bands. Within the visible region the mercury spectrum consists of four principal wavelengths which result in a greenish-blue light at efficiencies of 30 to 65 lumens per watt. While the light source itself appears to be a bluish white, there is an absence of red radiation in the low- and medium-pressure lamps and most colored objects appear distorted in color value. Blue, green, and yellow colors in objects are emphasized; orange and red appear brownish or black. For this reason and because several minutes may be required for restarting after a momentary interruption in current, mercury lamps are often combined with incandescent lamps in installations where it is desired to approximate average daylight conditions.[22] A summary

of existing technical data on the common types of mercury-vapor lamps is given in Table 6-5.

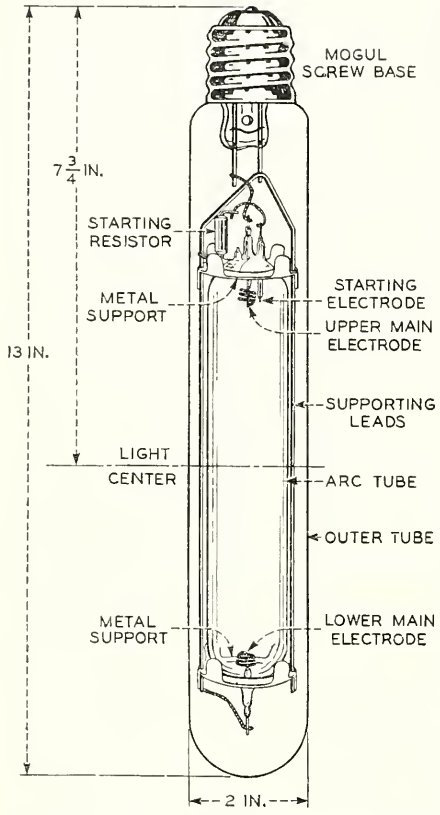


FIG. 6-15. Type A-H1, 400-watt, mercury -vapor lamp.

Types A-H1 and B-H1. The 400-watt, type A-H1 lamp is the most widely used of all mercury lamps, and is employed frequently in factory lighting, exterior floodlighting, and street lighting. As shown in Fig. 6-15, two main electrodes are located at opposite ends of the 7¾-inch glass tube in which the mercury that maintains the arc is vaporized. These electrodes are of coiled tungsten wire, covered with a barium-strontium oxide.

The arc tube contains a small amount of pure argon gas which is used as a conducting medium to facilitate the starting of the arc before the mercury is vaporized. Near the upper end of the tube is a starting electrode which is connected electrically to the lower electrode through a resistor. When current is applied, an electric field is set up between the starting electrode and the upper main electrode, causing an emission of electrons from the active surface of the main electrode. This imparts energy to the gas in the arc tube so that it becomes conducting.

The quantity of mercury in the arc tube is measured so as to maintain a vapor pressure approximately equal to one atmosphere.

The 400-watt arc tube is enclosed in a larger tubular bulb which reduces the effect of ambient temperature. About half an atmosphere of nitrogen is introduced in the space between the arc tube and the outer bulb.

Type A-H1 is for base-up operation. *Type B-H1* is for base-down operation. The chief difference is in the relative position of arc tube sealing-tip and base. In both types the arc tube is mounted so that the sealing tip is at the top in order that none of the mercury will be pocketed, which might interfere with its complete vaporization, reduce the mercury-vapor pressure below normal, and result in lower efficiency. Both types must be operated in a vertical position in order to keep the arc stream in the center of the tube. If the lamp axis is deviated from vertical more than 10 degrees, the arc stream will bow until it touches the side of the tube, at which point it will quickly melt the glass and ruin the lamp.

Table 6-5. Characteristics of Several Mercury-Vapor-Discharge Lamps Used in General Lighting

DESIGNATION* →	A-H1 B-H1 F-H1	A-H4	C-H5	A-H6¶	A-H9	E-H1	A-H12
Lamp watts (rated)	400	100	250	1,000	3,000	400	1,000
Watts, with single-lamp transformer	452	120	290	1,095	3,220	450	—
Watts, with two-lamp transformer	440/lamp	—	286/lamp	—	—	—	—
Lumens at 100 hours	16,000	3,000	10,000	—	120,000	20,000	60,000
Lumens (approx. initial)	16,000	3,000	10,000	65,000	120,000	20,000	60,000
Lamp lumens per watt at 100 hours	40	30	40	65**	40	50	60
Over-all lpw (single-lamp transformer)	35.4	24.4	34.5	59.4	37.3	44.2	—
Rated average life (hours)							
5 hours per start	4,000	1,000	2,000	75	3,000	2,000	2,000
10 hours per start	6,000	—	3,000	—	—	3,000	—
Outer bulb size	T-16	T-10	T-14	T-2	T-9½	T-20	T-28
Outer finish	Clear	Clear	Clear	Clear	Clear	Clear	Clear
Base type	Mogul‖	Admed.	Mogul	$\frac{3}{16}$-in. sleeve	S-c term.	Mogul screw	Mogul screw mech.
Burning position	†	Any	Any	Horiz.	Any	Any	Any
Max. over-all length (inches)	13	$5\frac{5}{8}$	8	$3\frac{1}{2}$	$54\frac{7}{8}$	11	14
Light center length (inches)	$7\frac{3}{8}$	$3\frac{7}{16}$	5	—	—	7	9
Vapor pressure (atmospheres)	1.2	8	4–4.5	110	0.55	2.5	1.5
Number of electrodes	3	3	3	2	2	3	3
Arc length (inches)	6	1	$1\frac{5}{8}$	1	48	$2\frac{3}{4}$	5
Arc tube material	Glass	Quartz	Quartz	Quartz††	Glass††	Quartz	Quartz
Supply voltage (primary volts)‡	115, 230	115, 230	115, 230	115, 230	230, 460, 575	115	115
Lamp-operating volts	136	130	135	840	535	135	135
Transformer secondary open circuit voltage	220	247	250	1,200	850	220‡‡	220‡‡
Lamp-starting current (amperes)	4.7	1.3	2.9	2.5	9.3	4.7	12
Lamp-operating current (amperes)	3.2	0.9	2.1	1.4	6.1	3.2	8.2
Power factor (per cent on lag circuits)§	60, 90, 95	50, 90	50, 90, 95	—	90	—	—
Starting time to full output	7 min	3 min	4 min	3 sec	7 min	4 min	4 min
Restarting time	7 min	3 min	4 min	2 sec	8 min	4 min	6 min

* The suffix number indicates the transformer required. (Examples A-H4, B-H4, C-H4, and S-4 all operate on an H4 transformer).

† *Burning position.* A-H1 and F-H1 are for base-up burning, B-H1 is for base-down burning. These types must be operated within 10 degrees of vertical.

‡ *Supply voltage.* Transformer design is centered for the range of standard voltage circuits.

§ *Power factor.* The higher power factor is obtained with transformers incorporating integral correction. Transformers for operating two lamps of types A-H1, B-H1, A-H5, and C-H5 have an over-all power factor of 95 per cent.

‖ The F-H1 lamp is designed for street-lighting service and, except for a mechanical-type base, it has the same characteristics as the A-H1.

¶ A-H6 is water-cooled and requires a water jacket of quartz or heat-resisting glass. B-H6 is air-cooled and rated at 900 watts. Its characteristics are similar to the A-H6.

** Initial lumens per watt (life less than 100 hours).

†† Single bulb lamp; the outer bulb is the arc tube.

‡‡ For normal indoor use. Higher open circuit voltages are desirable for dependable starting at lower temperatures.

The starting characteristics of type A-H1 are shown in Fig. 6-16. When the current flows the argon arc is seen for a few seconds as a bluish glow that fills the entire arc tube. The voltage rapidly increases until the lamp reaches a stable operating condition. This takes place in about 7 minutes, at which time all of the mercury is completely vaporized and the lamp operates at about 136 volts, 3.2 amperes. At this stage the arc no

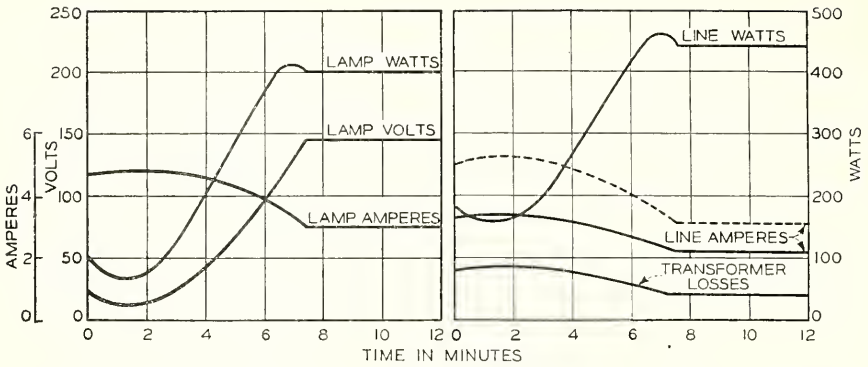


FIG. 6-16. Starting characteristics of type A-H1, 400-watt, mercury-vapor lamps.

longer fills the tube but is concentrated in a pencil-like arc stream of high brightness centered in the inner bulb. At full brightness the lamp produces approximately 16,000 lumens.

If the current is interrupted while the lamp is in operation, the lamp cannot be relighted for about 7 minutes. In this time it will cool enough to reduce the mercury-vapor pressure sufficiently to allow the arc to strike again. If the circuit is not broken this will occur automatically.

Type A-H1 lamps must be operated within rather close voltage limits, and transformer taps are provided for satisfactory operation over a wide range of line voltages. For best performance mercury-vapor lamps should not be operated from line voltages more than 5 per cent above or more than $2\frac{1}{2}$ per cent below the rated tap voltage of the transformer involved. The effects of voltage on operating characteristics of type A-H1 lamps are shown in Fig. 6-17.

Type E-H1. This type has an inner quartz bulb for applications requiring operation in a horizontal position or at an angle larger than 10 degrees from the vertical. The lamp produces 20,000 lumens.

Type H4. The 100-watt, type A-H4 lamp shown in Fig. 6-18 is sometimes referred to as a "capillary" lamp because the arc discharge takes place within a small capsule-like tube of quartz. This construction with short arc length and small diameter allows operation at high vapor pressures and temperatures. The outer bulb serves merely as a protective container and can be of any convenient size or shape.

Type H4 comes up to full brightness in from 2 to 3 minutes, starting with a blue (argon) glow and gradually assuming its normal operating color and efficiency. The arc will be extinguished in event of current interruption but will restart automatically after a cooling period of 2 to 3 minutes. These lamps will remain in operation even with a 20 per cent decrease from normal operating voltage, showing, in this respect, considerably more stability than the type A-H1 lamp. However, they will not start at such a low voltage.[23]

Type H5. The type H5 mercury-vapor lamp is a 250-watt capillary source similar in construction to type H4 but with longer bulbs and bases.

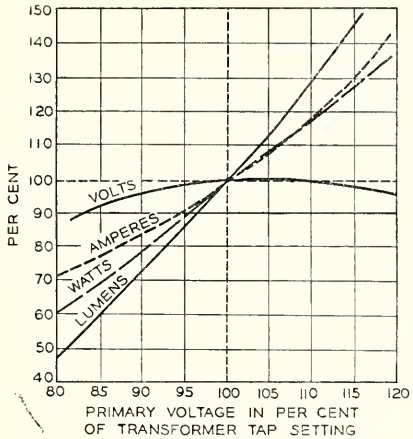


FIG. 6-17. Effect of voltage on the operating characteristics of type A-H1, 400-watt, mercury-vapor lamps.

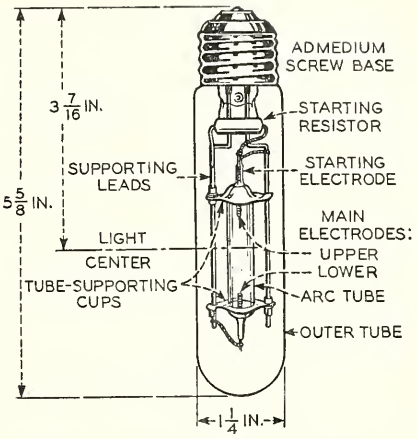


FIG. 6-18. Type A-H4, mercury-vapor lamp.

Type H5 produces 40 lumens per watt. The type C-H5 lamp has been employed to some extent for outdoor floodlighting and highway tunnel lighting.

Type H6. The 1,000-watt, type A-H6 mercury lamp consists of a capillary quartz tube about $1\frac{1}{2}$ inches long, having an outside diameter of $\frac{1}{4}$ inch and a bore of $\frac{3}{32}$ inch. Sealed into each end is a tungsten wire which serves both as electrode and lead. The tips of these wires project just through the surface of a small mercury pool in each end of the lamp. The pressure in the capillary when the lamp is not operating is about one fifteenth of an atmosphere, the pressure of the argon gas with which the lamp is filled. The lamp reaches its full brightness in 1 or 2 seconds after power is applied, the heat from the arc quickly vaporizing the mercury and building up the pressure to about 110 atmospheres (1,620 pounds per square inch).[24]

Because of the high wattage concentrated in such a small volume, in order to maintain reasonable operating temperature it is necessary that water be passed over the capillary tube fast enough to prevent the formation of steam bubbles on its quartz surface. To accomplish this, a "velocity tube" is placed around the lamp with a very small radial clearance through which the water must flow. Because the cross section of the water path is so restricted, sufficient velocity to prevent steam formation is attained with a water flow of about 3 quarts per minute. More than 90 per cent of the infrared radiation is absorbed by the circulating water.

The lamp produces 65,000 lumens with a maximum surface brightness of 195,000 candles per square inch (one fifth the brightness of the sun). Because heat storage is small and cooling rapid, type H6 lamps may be restarted at once after the current has been turned off. During life, the lamp voltage gradually increases and the current and the wattage decrease.

The life depends on the number of times the lamp is started and the type of service. There may be more variation in the life of individual lamps of type H6 than in the life of lamps of other types.

Type H9. The 3,000-watt, type A-H9 mercury lamp is a tubular source about $1\frac{3}{16}$ inches in diameter and $54\frac{7}{8}$ inches in length over all. The light source length is about 48 inches. The lamp has a porcelain base at either end with single-contact terminals. The rated life is 3,000 hours, based on 5 hours operation per start. Its initial light output rating (after 100 hours operation) is approximately 120,000 lumens.

Type A-H9 requires about 7 minutes to reach full light output under normal conditions. If the current is interrupted or drops sufficiently to extinguish the arc, about 8 minutes cooling will be required before the arc will restrike.

Mercury-vapor-discharge lamp auxiliary equipment. Ballast for type H1, H4, H5, and H6 lamps is provided in the form of step-up autotransformers with voltages sufficiently high to establish the arc without external starting mechanisms. Magnetic shunts or separate reactors are used as a means of regulating the lamp currents. Power factor correction is obtained by primary capacitors in the case of single lamp units and, where two lamps are operated from a single ballast, by phased circuits. Figure 6-19 shows typical circuits.

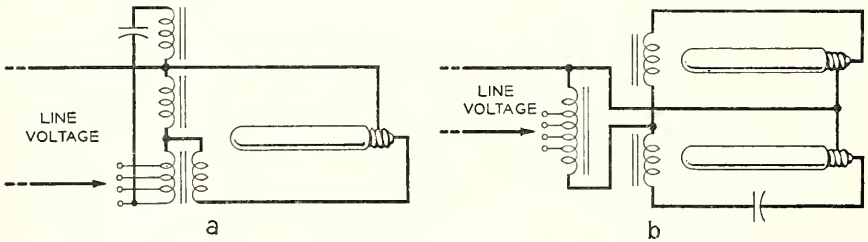


FIG. 6-19. Typical circuits for operating mercury vapor lamps: (a) single-lamp circuit; (b) two-lamp circuit.

Transformers for the type A-H9 lamp are made for 115-, 230-, 460-, and 575-volt circuits. All have taps for 95, 100, and 105 per cent of rated line volts and include a built-in capacitor for power factor correction. The autotransformer and connection leads are carried into a wiring compartment for direct conduit connection of line and lamp. The total power consumed by lamp and transformer is about 3,220 watts for the 230-volt transformer.[21]

Sodium-Vapor Discharge Lamps

Electric discharge lamps using sodium vapor possess inherent possibilities for high luminous efficiency because the wavelength of the monochromatic yellow radiation from such a discharge is very close to that of maximum luminosity in the spectrum. Efficiencies of 100 lumens per watt have been obtained with experimental sodium lamps and 50 lumens per watt is secured in practice. The two sodium lamps in commercial use

at present are the 180-watt, 10,000-lumen lamp and the 145-watt, 6,000-lumen lamp. These are applied principally to street and highway lighting and can be used on either series or multiple circuits.[25]

The 10,000-lumen lamp shown in Fig. 6-20 consists of a tubular inner bulb about 12 inches long and about 3 inches in diameter placed within a double-walled vacuum flask to maintain the proper temperature. The inner bulb contains a small quantity of sodium, and some neon gas to facilitate starting. Coiled filaments at either end serve as cathodes with one side of each filament connected to molybdenum anodes. Four base contacts are required. This lamp has an average life of 3,000 hours under normal street or highway lighting service. It has a starting voltage of 50, a normal operating voltage of 30, and a current rating of 6.6 amperes.

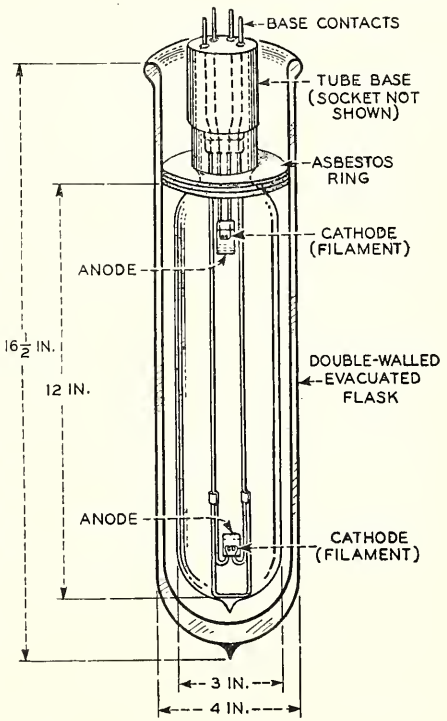


FIG. 6-20. 10,000-lumen, sodium-vapor lamp.

On closing the lamp circuit to begin the starting operation a time-delay relay allows the cathodes to heat. Then the circuit is broken and the induced voltage of the transformer starts a discharge of a characteristic red color through the neon. As the temperature rises the sodium evaporates and gradually the sodium vapor discharge comes up to its full brightness and normal yellow color. This warm-up requires about 30 minutes.

The auxiliary equipment for street series operation of the 10,000-lumen sodium lamp consists of a time-delay switch arrangement for preheating the cathodes and a radio interference suppressor. For operation on multiple circuits a reactive ballast must also be provided since the multiple circuit does not regulate the current.

A sodium lamp for laboratory work is also available. The total input is 60 watts and the lamp itself consumes 28 watts. The high-resistance ballast used with this lamp results in some sacrifice in efficiency but ensures the stability of operation necessary for laboratory measurements.

Miscellaneous Electric Discharge Lamps

Glow lamps. These lamps, which may have a rating as low as 0.3 lumen per watt, are impractical sources for general illumination, but they are often used as signal, pilot, or night lights. The typical lamps shown in

Fig. 6-21 emit light having the spectral character of the inert gas with which they are filled. The glow occurs around the negative electrode where free electrons strike atoms of the gas and cause them to radiate.[26]

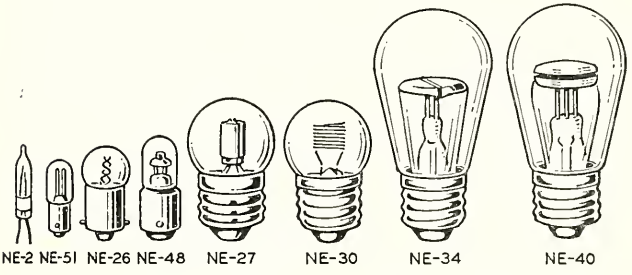


FIG. 6-21. Typical glow lamps.

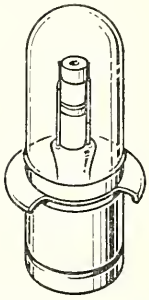


FIG. 6-22. Type CR-1 crater lamp.

Glow lamps will operate on alternating-current or direct-current circuits at voltages as low as 70. Like other discharge lamps, glow lamps require a limiting resistance in series. In screw-base lamps this resistor is incorporated in the base or in the bulb; in the case of bayonet-base lamps, which are manufactured without a resistor, the proper resistance must be supplied externally. The operating characteristics of several typical glow lamps are given in Table 6-6.

Table 6-6. Operating Characteristics of a Typical Glow Lamp

TYPE	RATED VOLTS	AVERAGE STARTING VOLTS*		WATTS	BULB	BASE	ELECTRODES	RESISTANCE	GAS	MAX. OVER-ALL LENGTH (inches)	AVERAGE USEFUL LIFE (hours)
		A.C.	D.C.								
AR-3	105–125 A.C.†	80	115	0.25	T-4½	Cand. screw	P-3	In base	Argon	1½	1,000
AR-5	105–125 A.C.†	80	115	0.25	T-4½	Blue slide	P-3	In base (20,000 ohms)	Argon	$1\frac{7}{16}$	3,000
NE-2	105–125	65	90	0.04	T-2	Unbased§	W-11	External	Neon	$1\frac{1}{16}$‡	25,000
NE-3	105–125	65	90	0.04	T-2	Unbased§	W-11	In lead	Neon	$1\frac{1}{16}$‡	3,000
NE-16	105–125		67–87‖	0.25	T-4½	D-c. bay.	P-3	External	Neon	1½	3,000
NE-20	105–125	60	85	1.00	G-10	Med. screw	PW-5	In base	Neon	$2\frac{1}{16}$	3,000
Fluorescent	110–125 A.C.	100	140	1.00	S-11	Two-prong or med. screw					3,000
Fluorescent KR-1	110–140 A.C. 150–175 D.C.	100	140		G-6	Cand. screw	W-10	50,000 ohms	Krypton		3,000
Fluorescent Xmas tree	110–125			4	G-16	Candelabra skirted screw	Special			$3\frac{3}{8}$	1,000

* At 0 hours operation.
† May be operated on 135-volt, d-c circuits.
‡ Glass parts only.
§ Lamps have wire terminals $\frac{11}{16}$-inch long not included in MOA length. Resistance where specified is set into one lead wire $\frac{5}{16}$-inch from end of glass seal.
‖ Direct-current operating voltage at 1.5 milliamperes, 53–65 volts.

Argon, *Neon*, and *fluorescent* glow lamps are available. In the fluorescent type the energy output of the discharge in the 0.01 to 0.1 micron wavelength Schuman ultraviolet region is sufficiently independent of ordinary ambient temperatures that these lamps may be operated satisfactorily out of doors in winter weather.

Crater lamps. These lamps, shown in Fig. 6-22, emit the characteristic lines of the neon spectrum from an arc between the central "crater" cathodes and the surrounding ring anode. They operate in series with a ballast resistor on direct current; their output may be modulated rapidly.

Concentrated-arc lamps. These lamps are a type of direct-current discharge lamp made with permanent, fixed electrodes sealed into an argon-filled glass bulb. The light source is a small spot (0.003 to 0.059 inch in diameter) of incandescent zirconium which forms on the end of a zirconium-oxide-filled tantalum tube, (the negative electrode). See Fig. 6-23.

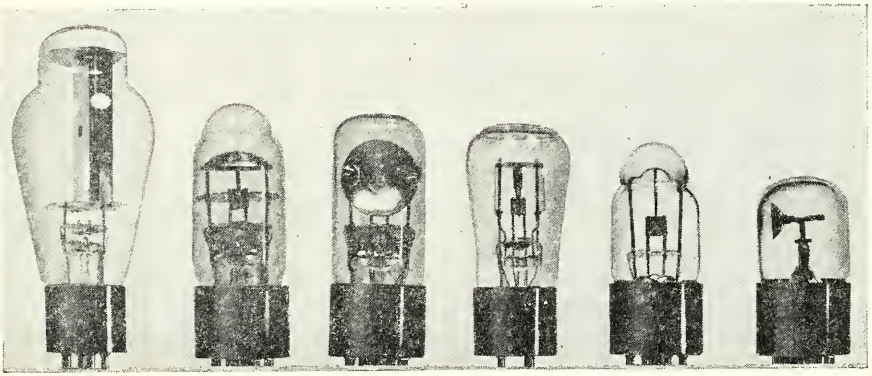


FIG. 6-23. Concentrated arc lamps.

The radiation is distributed throughout the visible, ultraviolet, and infrared portions of the spectrum between 0.3 and 4.0 microns and has a cosine type of spatial distribution.[27]

Special starting and operating circuits, including a resistance ballast, are required. See Table 6-7.

Table 6-7. Operating Data on Standard Sizes of Concentrated-Arc Lamps

NOMINAL LAMP RATING (watts)	VOLTS	AMPERES	LIGHT SOURCE DIAMETER (inches)	BRIGHTNESS (candles per square inch)		MAXIMUM CANDLE POWER	LIFE* (hours)	BULB	BASE		MAXIMUM TEMPERATURE (degrees F)	
				Maximum	Average				Type	No. Pins	Bulb	Base
2	37	0.055	0.003	62,000	36,000	0.32	175	T-5	Min.	3	140	100
10	21	0.5	0.016	35,400	14,200	2.7	700	T-9	Small	8	225	130
25	20	1.25	0.029	26,000	13,600	8.7	800	T-9	Small	8	355	145
100	15.4	6.25	0.059	33,600	25,200	77.0	1,000	ST-19	Med.	4	470	160

* Average life obtained under laboratory conditions.

Flashlamps or flashtubes. As their name suggests these lamps are designed to produce high brightness flashes of light of extremely short duration. A flashlamp is a tube of glass or quartz which has an electrode in each end. The tube is filled with gas, usually xenon. The spectral distribution of light from an xenon discharge is similar to that of average daylight. (See Fig. 6-24.) Other gases employed include argon, hydrogen, and krypton. Typical time-light curves for xenon-filled lamps are shown in Fig. 6-25.

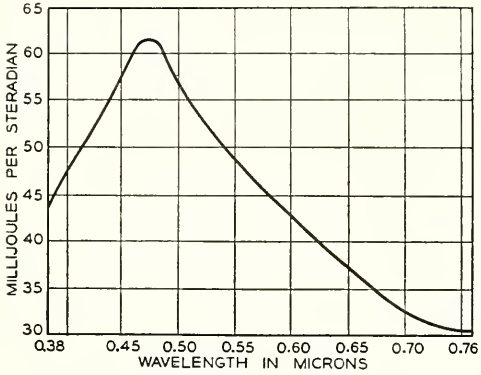


FIG. 6-24. Spectral energy distribution curve of typical xenon-filled flash lamp (radiation in direction perpendicular to helix).

1 micron = 10,000 angstroms = 1/10,000 centimeter

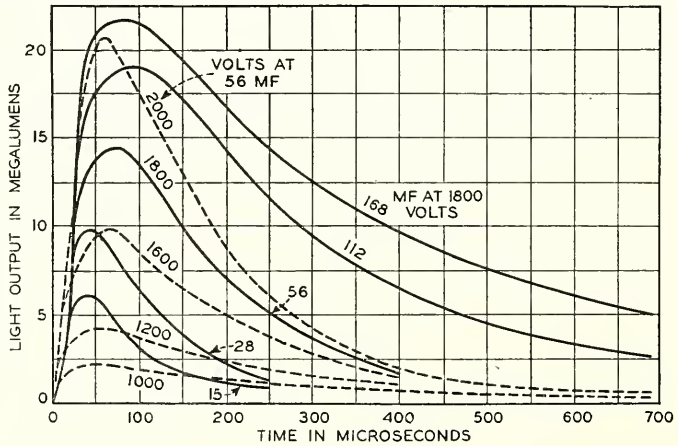


FIG. 6-25. Time-light curves for a flash lamp at various capacitance and voltage levels.

Several straight tubular lamps have been developed for use in trough reflectors. For most applications, however, more concentrated forms are preferred. As with tungsten filaments, improved concentration is obtained by coiling the tube in the form of a helix. Three sizes of helices have been used with different bulb and base combinations to make the typical lamps shown in Fig. 6-26. Lamps differ in types and sizes of electrodes, type of gas with which the tube is filled, filling pressure, and tube material; also, different electrical circuits are used for flashing the lamps.[28]

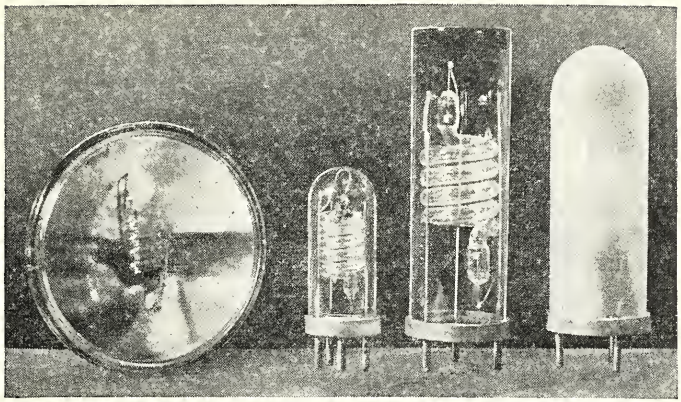


FIG. 6-26. Flash lamps mounted in typical enclosures.

Power supply. The basic elements include a step-up transformer and a rectifier to obtain the high-voltage direct current required to charge the condenser and some means of limiting the charging current of the condenser to the safe limits of the rectifying tubes and transformers. This limiter may be either a resistor or reactor connected in series with the condenser on the charging side or a high-leakage reactance characteristic in the step-up transformer itself. A typical circuit is shown in Fig. 6-27.

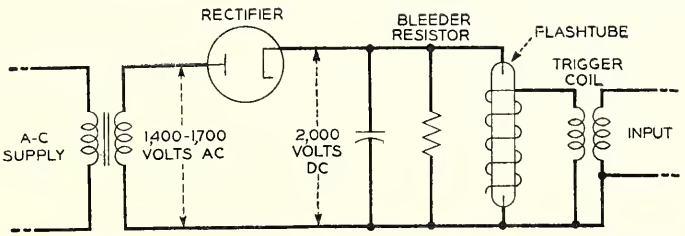


FIG. 6-27. Basic elements of typical flash-lamp power supply.

In one type of flashing circuit an extremely high potential (of the order of 10,000 volts or more) is momentarily applied to the wall of the tube, producing a brilliant flash of light of extremely short duration. When the condenser charge has been almost entirely expended, the voltage across the terminals drops to a low value, the tube ceases to conduct, and the condenser proceeds to accumulate the charge required for the next flash.

Another circuit utilizes flashlamps which operate without separate ionizing potential. In this type the lamp is not connected across the terminals of the condenser until it is desired to flash the tube and the tube itself is designed to flash over at the potential of the charge in the condenser. The power-supply design is thus simplified, but it is necessary to employ a switch which can handle the high voltages and momentarily high currents involved.

Limits of energy input. For single-flash operation, the limit to the amount of energy which can be consumed depends upon the desired lamp

life, that is, the total number of useful flashes. This is affected by the rate of tube blackening and destruction of the tube or its parts.

If a flashtube is operated repetitively and rapidly at the maximum energy input level so that its temperature rises excessively, it will either miss (fail to flash) or become continuously conductive. In the latter case the tube may be damaged. The total watts consumed are the product of the watt-seconds per flash and the number of flashes per second. The figures for a tube operating at 2,000 volts and 112 microfarads (224 watt-seconds per flash) are tabulated below for different rates of flash:

Flashing Rate	*Input to Lamp (Watts)*
One flash per minute	3.7
One flash per 10 seconds	22.4
One flash per second	224.0
Ten flashes per second	2240.0
One hundred flashes per second	22,400.0

Where repetitive flashing is necessary the power input per flash to the tube must be reduced as the rate of flashing is increased.

FLUORESCENT LIGHT SOURCES

Fluorescent light sources which emit light in a variety of colors include the mass-produced types (Fig. 6-28) and custom-made types also. Both utilize cylindrical glass tubing coated inside with fluorescent phosphors. In each type an electrode is sealed in at each end and, after evacuation of the tube, a small drop of mercury is added and a volume of neon or argon is introduced at low pressure (3 to 18 millimeters of mercury, depending on the lamp).

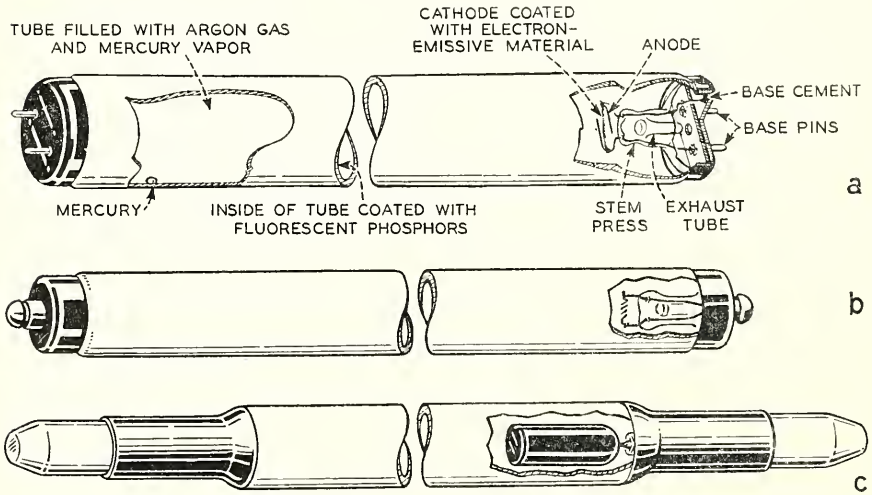


FIG. 6-28. Cutaway view of fluorescent lamps showing typical electrodes and bases: (a) filament (hot) cathodes (preheat starting); (b) filament (hot) and (c) cylindrical (cold) cathodes (instant starting).

The relationship between mercury vapor pressure and current density inside a lamp and the voltage supplied by the electrical circuit is chosen so that under normal operating conditions the output of the arc discharge through a lamp is largely in the 0.2537-micron-wavelength ultraviolet-spectrum line, which is presently the most efficient in producing fluorescence.[29]

Most of the many straight and circular lamp types mass-produced in the United States are standardized with respect to their nominal photometric, color, electrical, and mechanical characteristics. For the most part, different manufacturer's lamps of the standardized types are mechanically and electrically interchangeable.

Custom-made fluorescent lamps in several different diameters and colors are prepared on order in lengths and forms designed for a particular installation.

Fluorescent sources are electric discharge lamps. Like all other discharge lamps, they have a negative resistance characteristic and therefore must be operated in series with a current-controlling ballast. The type designed for use on low-voltage circuits with a special manual or automatic starting switch requires a short (3–4 second) preheat period after closing the circuit before the arc strikes. Other types are designed for circuits which provide a higher starting voltage (400–15,000 volts). In these, the discharge starts instantly upon closing the circuit.

Fluorescent lamp bases. For satisfactory performance, each fluorescent lamp must be connected to an electrical circuit with proper voltage and current characteristics for its type. Therefore, different lamps are made with different bases, as shown in Fig. 6-28. When the proper lamp holders are wired to a particular type of ballast and properly spaced, only the lamp type for which that ballast was designed may be inserted in the circuit. Typical lamp holders are shown in Fig. 6-29.

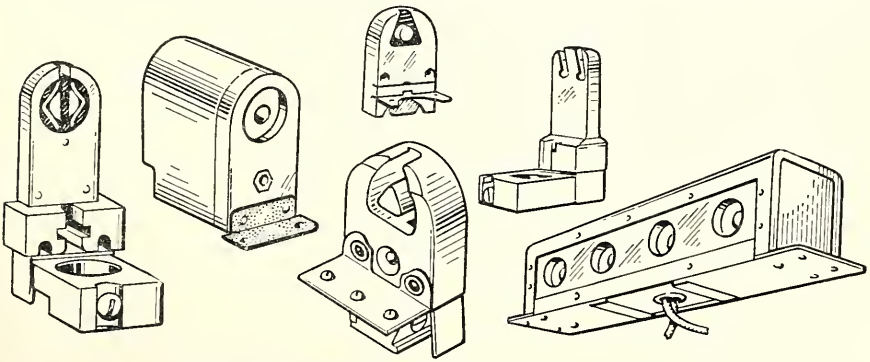


FIG. 6-29. Typical holders for fluorescent lamps.

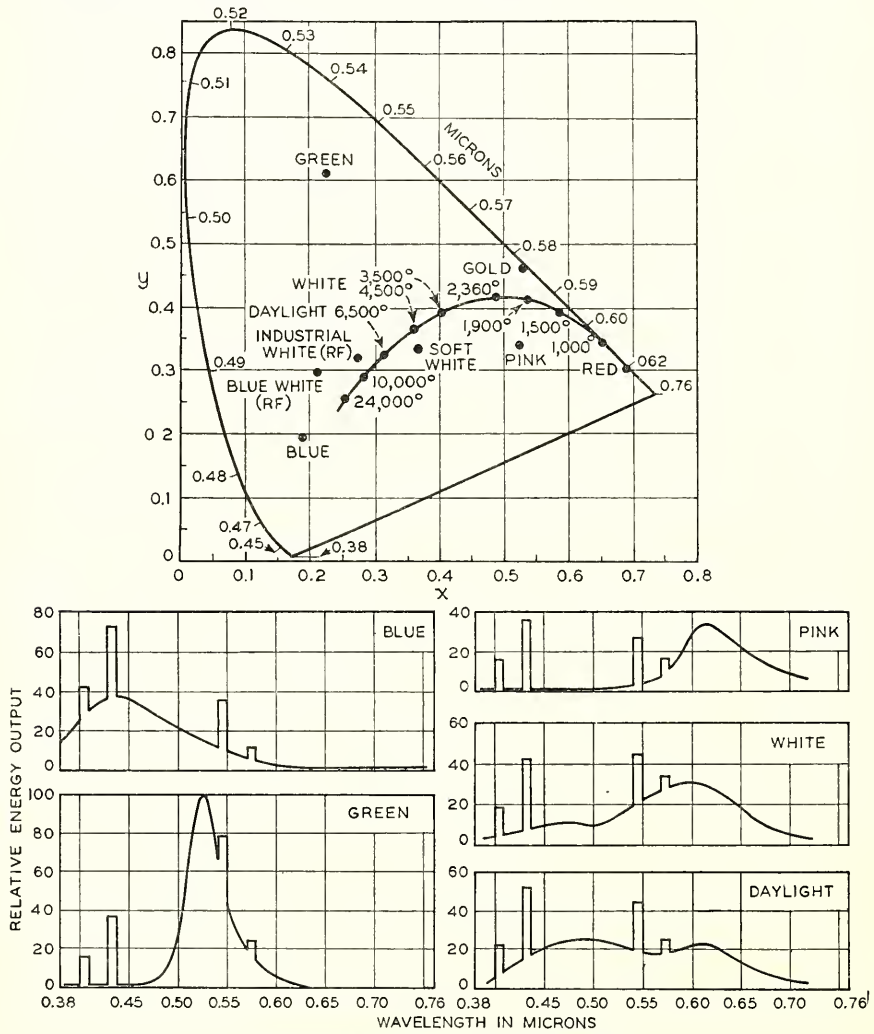
Fluorescent lamp performance. Performance characteristics of fluorescent lamps which are of general interest and importance include:

Initial light output (lumens after 100 hours operation).

Efficiency (lumens per watt consumed).

Lumen maintenance throughout life (per cent of initial value).
Color (spectral distribution, I.C.I. co-ordinates).
Speed and dependability of starting.
Stroboscopic effect. Brightness (footlamberts).
Radio interference. Useful life in service (hours).

Data on typical lamps of a variety of types are given in Fig. 6-30 and in Tables 6-8, 6-9, and 6-10. So far as possible, data presented on types produced by several manufacturers represent industry averages. Since these data are likely to differ slightly from specific figures on one manufacturer's product, it is advisable to check the manufacturer's data sheets for detailed information on current production.[30]



1 micron = 10,000 angstroms = 1/10,000 centimeter

FIG. 6-30. I.C.I. *x-y* co-ordinates and spectral distribution curves of light from typical fluorescent lamps.

Table 6-8. Performance Data on Typical Filament (Hot) Cathode, Preheat-Starting, Fluorescent Lamps*

Approx. lamp watts†		4	6	8	13	14	15	15	20	30	32	40	100
Nominal length (inches)‡		6	9	12	21	15	18	18	24	36	§	48	60
Bulb‖		T-5	T-5	T-5	T-5	T-12	T-8	T-12	T-12	T-8	T-10	T-12	T-17
Base (bipin)		Min.	Min.	Min.	Min.	Med.	Med.	Med.	Med.	Med.	4 pin	Med.	Mog.
Approx. lamp amperes		0.127	0.152	0.170	0.160	0.372	0.302	0.332	0.357	0.342	0.42	0.410	1.45
Approx. lamp volts¶		36	46	57	95	42	56	48	61	103	85	107	73
Max. starting amperes		0.18	0.24	0.27	0.27	0.65	0.65	0.65	0.65	0.65	—	0.75	2.20
Rated life (hours)** and lumen maintenance (per cent initial lumens) for daylight and white lamps at 70% rated life	hrs/ start												
	3	2,500	2,500 75%	2,500 75%	2,500	2,500 85%	2,500 78%	2,500 84%	2,500 84%	2,500 78%	2,500	2,500 84%	3,000 78%
	6						4,000 72%	4,000 76%	4,000 76%	4,000 72%	1,600	4,000 76%	4,500 72%
	12						6,000 69%	6,000 70%	6,000 70%	6,000 69%		6,000 70%	6,500 69%
Initial lumens:													
White		73	210	330	582	490	622	600	940	1,485	1,600	2,310	4,300
Daylight		68	185	295	505	420	555	517	800	1,350		1,960	3,900
Soft white						365	487	472	720	1,170		1,760	3,350
4,500° white			200	310	547	460	585	570	860	1,380		2,110	4,000
Blue							315	300	460	780			
Green							900	855	1,300	2,250			
Yellow green									1,080			2,600	
Pink							300	285	440	750			
Gold							375	355	540	930			
Red							45	42	60	120			
Footlamberts:													
White			2,615	2,775	2,690	1,390	2,060	1,420	1,515	2,370	2,040	1,750	1,965
Daylight			2,345	2,495	2,330	1,180	1,905	1,275	1,330	2,140		1,570	1,840
Soft white						975	1,560	1,100	1,175	1,870		1,373	1,580
4,500° white			2,470	2,770	2,526	1,310	2,030	1,290	1,360	2,120		1,640	1,915
Blue							1,125	750	850	1,350			
Green							3,200	2,610	2,400	3,900			
Pink							1,050	720	800	1,300			
Gold							1,650	900	1,000	1,600			
Red							160	110	110	210			

* Industry averages. Lack of complete data from all sources results in some discrepancies within the table,
† Wattage consumed by auxiliary must be added to get total.
‡ Includes lamp and two sockets.
§ Circular lamp 12 inches diameter.
‖ Figures indicate maximum outside diameter in eighths of an inch.
¶ 110- to 125-volt circuit ballasts available for all types, higher voltage ballasts for some.
** Average life under specific test conditions.

Table 6-9. Performance Data on Typical Filament (Hot) Cathode Instant-Starting, Fluorescent Lamps*

Nominal length (inches)†	42		48	64		72		96	
Maximum lamp length (inches)	40		¶	62		70		94	
Bulb designation‡	T-6		T-12	T-6		T-8		T-8	
Open circuit voltage	450		440	600		575		725	
Lamp current (milliamperes)	100	200	41	100	200	100	200	100	200
Rated life (3 hours operation per start) hours§	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500
Lamp watts‖	15	26	40	24	39	22	38	29	51
Approximate lamp volts	175	147	108	277	230	247	217	335	292
Initial lumen output (white)	915	1,400	2,300	1,410	2,100	1,405	2,350	1,920	3,250
Footlamberts (white)	1,680	2,590	1,750	1,670	2,560	1,050	1,755	1,065	1,790

* Industry averages.
† Includes lamp and two sockets.
‡ Figures indicate maximum outside diameter in eighths of an inch.
‖ Wattage consumed by auxiliary must be added to get total.
§ Six hours operation per start, 4,000 hours; twelve hours operation per start, 6,000 hours.
¶ Same as 40-watt hot cathode lamp in table 6-8.

Table 6-10. Performance Data on Typical Cylindrical (Cold) Cathode, Instant-Starting, Fluorescent Lamps*

OUTSIDE DIAMETER† (millimeters)	OPERATING CURRENT (milliamperes)	COLOR DESIGNATION	BRIGHTNESS‡ (footlamberts)	INITIAL LUMENS/FOOT‡ (100-hr operation)	VOLTS/FOOT§	WATTS/FOOT§	LUMEN MAINTENANCE (per cent initial lumens/foot) 2,000 hours	4,000 hours	6,000 hours	8,000 hours	10,000 hours
		3,500° White	300	74							
	24	Daylight¶	290	71	63	1.5					
		Warm white	330	80							
		3,500° white	550	142							
25	48	Daylight¶	500	132	57	2.7					
		Warm white	600	150							
		3,500° white	1,150	271			87	84	81	78	75
	96	Daylight¶	1,050	247	50	4.8	87	84	81	78	75
		Warm white	1,200	286			87	84	81	78	75
		3,500° white	460	87							
	24	Daylight¶	430	80	72	1.7					
		Warm white	500	94							
		3,500° white	950	172			93	89	87	85	83
20	48	Daylight¶	850	159	64	3.1	93	89	87	85	83
		Warm white	1,000	184			93	89	87	85	83
		3,500° white	1,700	322							
	96	Daylight¶	1,500	299	57	5.5					
		Warm white	1,850	339							
		3,500° white	860	108							
	24	Daylight¶	780	98	90	2.2					
		Warm white	870	110							
		3,500° white	1,400	190							
15	48	Daylight¶	1,350	172	81	3.9					
		Warm white	1,500	203							

* Industry averages supplied by the Fluorescent Lighting Association.

† Optimum pressure-diameter relationships with respect to the lumen output, life, and voltage of cylindrical (cold) cathode fluorescent lamps have been standardized by the Fluorescent Lighting Association along with over-all lengths of these lamps.[31]

FLUORESCENT LIGHTING ASSOCIATION STANDARDS

Diameter (mm)	7	8	9	10	12	15	18	20	25
Pressure (mm of mercury)	18	17	15	13	11	9	8	7	6
Over-all length (inches) (Subtract 4 to get luminous length)	52		64		76		84	93	116

‡ For gases No. 1050, No. 50, or No. B10 at standard pressure (for argon multiply by 0.96). For Argon at 4-millimeter pressure multiply by 0.87.

§ For luminous portion (over-all less 4 inches), assuming lamp power factor equals 100 per cent and neglecting voltage drop, wattage loss at electrodes, and ballast watts: To get *over-all lamp* voltage multiply volts per foot by length of luminous portion and add 105 (approximate electrode drop). To get *total* watts consumed by lamp and ballast multiply watts per foot by length of luminous portion and add both (voltage loss at electrodes 105 x operating current) and the ballast watts.

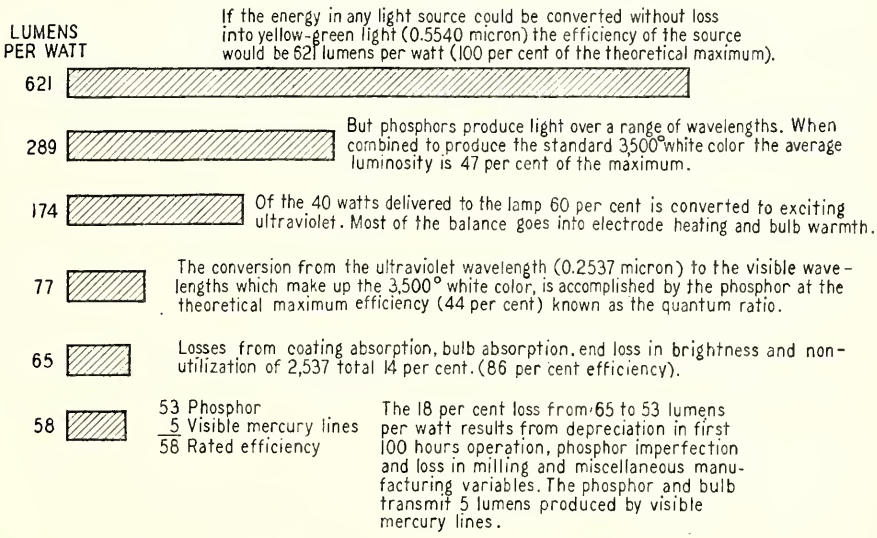
¶ Applies to soft white also.

Factors affecting fluorescent lamp performance. A number of variables have an appreciable effect on fluorescent lamp performance. As noted below these include external factors as well as design and manufacturing details:

Dimensions.	Lamp current.	Humidity.
Electrodes.	Bulb-wall temperature.	Surface treatment.
Inert-gas filling pressure.	Ambient temperature.	Hours in operation.
Lamp voltage.	Mercury vapor pressure.	Auxiliary equipment.
Arc watts per square inch of phosphor area.		Hours operation per start.

Fluorescent lamp light output and efficiency.

Several energy conversions take place when light is produced by a fluorescent lamp. As in other light sources today, a relatively small percentage of the power consumed is converted to light. See Fig. 6-31.



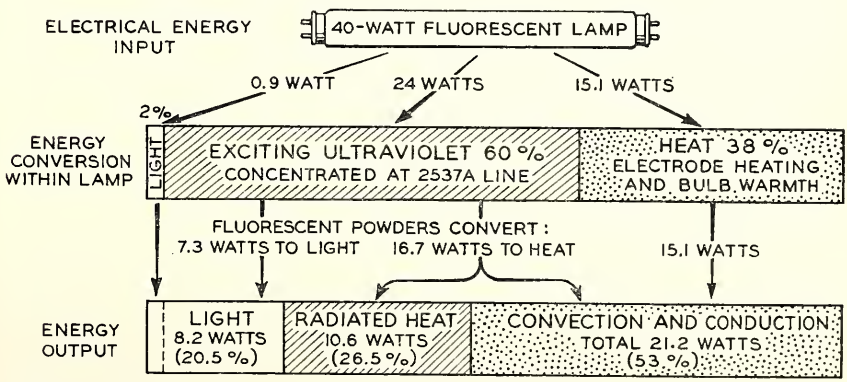


FIG. 6-31. Energy conversion efficiency and distribution in a typical preheat-starting, 40-watt, white fluorescent lamp.

Both design factors and operating conditions influence the efficiency with which the conversions take place and, therefore, the light output of any given lamp. Figure 6-31 shows the energy distribution and conversion efficiency characteristic of one typical filament (hot) cathode, preheat-starting type of fluorescent lamp under optimum operating conditions.

Arc length. Other things being equal, lumen-per-watt ratings of long lamps are greater than lumen-per-watt ratings of short lamps. Figure 6-32 shows the relationship between arc length and lumen-per-watt ratings for typical lamps.

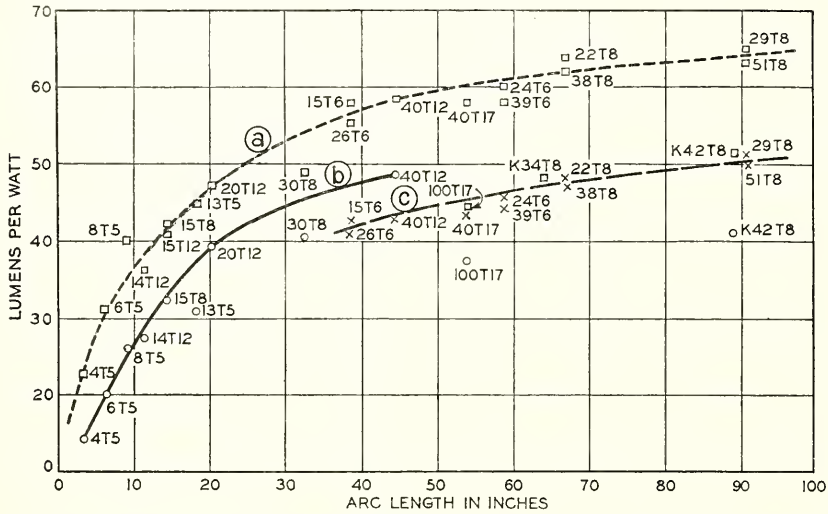


FIG. 6-32. Curve *a* shows lumen-per-watt ratings as a function of arc length for typical white fluorescent lamps. Curve *b* shows the effect of auxiliaries for operating preheat-starting lamps. Curve *c* shows the effect of auxiliaries for operating instant-starting lamps. The letter k indicates a cold cathode lamp.

This arc length-efficiency relationship is a result of the power consumed at the electrodes (lamp current times electrode voltage drop). A drop of about 18 volts occurs at filament (hot) cathodes, and a drop of about 105 volts occurs at cylindrical (cold) cathodes. Figure 6-33 shows the relationship between lamp voltage and arc length for typical lamps. The characteristic electrode drops for the two types of cathodes is indicated by the intersect of the curves with the ordinate corresponding to zero length.[32]

Lamp current. Curves in Fig. 6-34 show the relationship between lumens per watt and lamp current in milliamperes for typical lamps with diameters of 1, $1\frac{1}{2}$, and $2\frac{1}{8}$ inches. Analysis of lamp dimensions and current at the peak in each curve indicates that maximum light production efficiency is obtained when the energy dissipated in the arc is about 0.13 watt per square inch of phosphor area.[32]

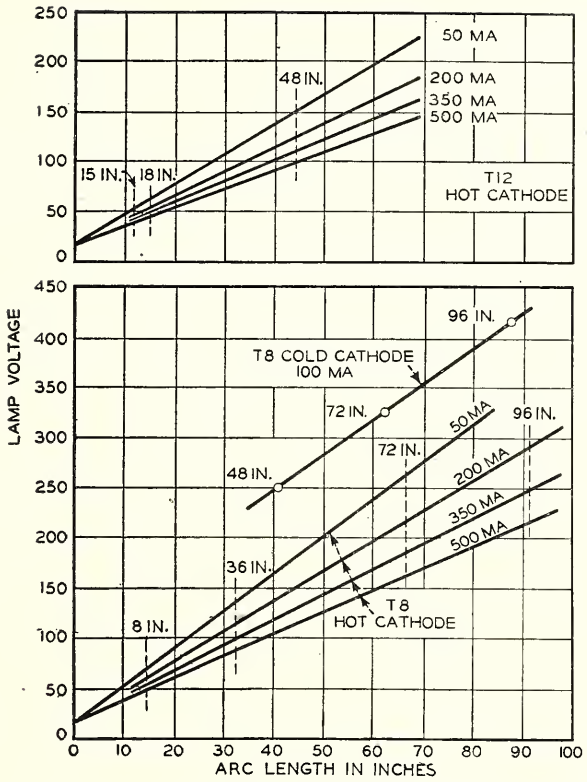


FIG. 6-33. Operating voltage of typical fluorescent lamps as a function of arc length.

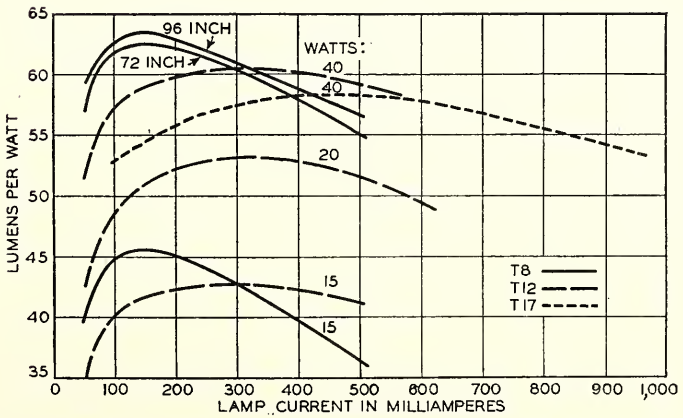


FIG. 6-34. Lumen-per-watt ratings of typical white fluorescent lamps as a function of lamp current.

Bulb wall temperature. Under the operating conditions for which common lamps are designed (still air at 80 degrees Fahrenheit ambient temperature), 0.13 watt per square inch brings bulb-wall temperature to 100 to 110 degrees Fahrenheit.

The mercury vapor pressure (6 to 10 microns of mercury) related to this bulb-wall temperature is that at which the 0.2537-micron wavelength line is generated most efficiently. At lower bulb-wall temperatures some of the mercury condenses and at the lower pressure the 0.2537-micron wavelength is produced less efficiently. At higher temperatures some of the energy radiated in the 0.2537-micron line is absorbed by the mercury vapor.[32] Therefore the lumen-per-watt rating of a fluorescent lamp is affected by operating conditions which deviate from the 80-degree-Fahrenheit, still-air conditions to which the nominal lumen-per-watt rating applies.[33]

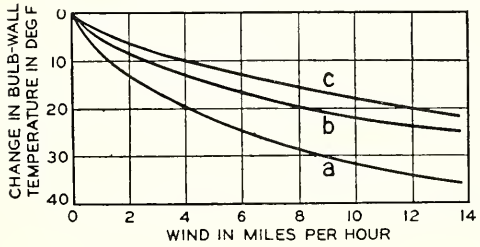


FIG. 6-35. The effect of air movement on fluorescent-lamp, bulb-wall temperature: (a) wind blowing directly on the lamp; (b) lamp shielded from the wind; (c) lamp enclosed in a glass sleeve ½ inch larger in diameter.

The change in bulb-wall temperature caused by air movement is shown in Fig. 6-35 for exposed lamps, shielded lamps, and lamps enclosed in a glass sleeve. The change takes place as a function of the air speed and is independent of ambient temperature.

The magnitude of the effect on light output of a change in bulb-wall temperature is not the same for all lamps, since, as shown in Fig. 6-36, not all are designed to have the 100–110 degree Fahrenheit wall temperatures associated with the optimum arc-power: phosphor-area ratio.

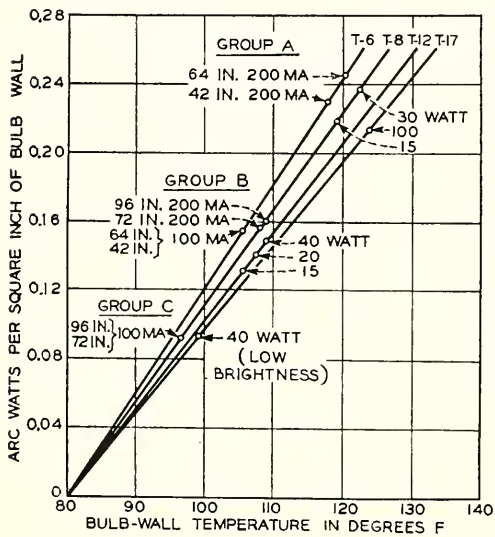


FIG. 6-36. The incident radiant power density (arc watts per square inch) on the bulb wall determines the bulb-wall temperature of lamps of a given diameter operating in still air (80 degrees Fahrenheit) at rated watts and amperes.

As shown in Fig. 6-37, the light output of lamps in groups *A* and *B*, which are designed to operate slightly above the optimum temperature under standard conditions, will increase slightly above rated values if the ambient temperature drops below 80 degrees Fahrenheit. A similar effect on the output of lamps in these groups will result from a reduction in bulb-wall temperature caused by air movement.

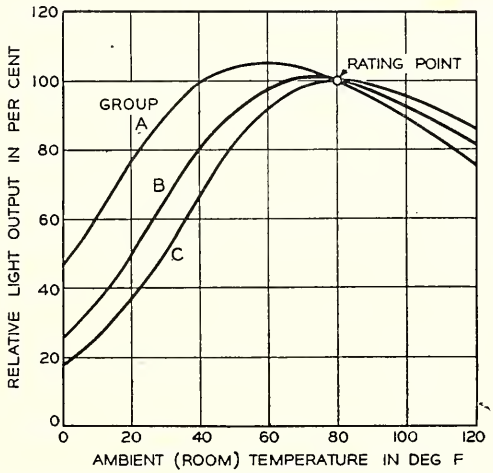


FIG. 6-37. Effect of ambient temperature on light output of the fluorescent lamps shown in Fig. 6-36 operating in still air at rated watts and current.

Luminaires tend to confine or restrict the normal passage of air around a lamp and therefore cause an increase in the bulb-wall temperature. Data for typical luminaires are given in Fig. 6-38.

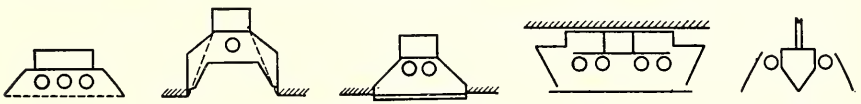


FIG. 6-38. Effect of typical luminaires on bulb-wall temperature of typical fluorescent lamps.[33]

	Luminaire	Temperature Rise (Fahrenheit)
a.	Open end industrial (two 40-watt T-12 lamps)	15
	Closed end industrial (two 40-watt T-12 lamps)	20
	Closed end industrial with slots (two 40-watt T-12 lamps)	15
	Closed end industrial (three 40-watt T-12 lamps)	35
b.	Troffer, aluminum (one 40-watt T-12 lamp)	20
	Troffer, white (one 40-watt T-12 lamp)	20
c.	Troffer, shallow, with glass cover (two 40-watt T-12 lamps)	25
d.	U.R.C. glazed (four 40-watt T-12 lamps: inside lamps)	40
e.	Any luminaire, open top and bottom, lamps separated by baffle and/or 6 inches apart	0

Operation of ordinary lamps at low ambient temperatures and in locations exposed to high winds results in below-optimum, bulb-wall temperatures and low lumen output per watt. However, a special lamp, designed and manufactured with a higher vapor pressure for operation at low temperature, may have quite good lumen output per watt under similar conditions. Starting difficulties encountered at low temperature with preheat-type lamps may be minimized by the use of a thermal switch starter.

Hours in operation. Like that of other light sources, the lumen output of fluorescent lamps decreases as the hours the lamps are operated increase. Although the exact nature of the change of the phosphor which causes the phenomenon is not understood, it is known that at least during the first 4,000 hours of operation the reduction in lumen output per watt is directly related to the arc-power: phosphor-area ratio.[32] This relationship in several typical lamps is shown in Fig. 6-39*a*. As would be expected, lamps with different arc power-phosphor area ratios have different lumen maintenance curves, as shown in Fig. 6-39*b*.

Fluorescent lamp life and lamp starting.

Hours operation per start. The oxide cathode coating must be in good condition to ensure proper starting at rated voltage of the preheat-starting fluorescent lamp. However, each time a preheat-type lamp is started a small amount of the oxide coating is consumed. A sufficient quantity of the material may be removed in about one thousand starts to cause starting failures. For this reason, the average life of these lamps is rated on the basis of hours operation per start. See Tables 6-9 and 6-10.

Because the proper starting of cylindrical (cold) cathode lamps depends primarily on a high voltage rather than on the oxide coating of the cathodes, the life of this type of lamp is not appreciably affected by starting frequency.

Effect of voltage and humidity on starting. To start a fluorescent lamp requires a higher voltage than is necessary to keep the lamp in operation once it has been started. Although all aspects of starting phenomena have not been explained, it is believed, on the basis of one theory which fits the available experimental data reasonably well, that capacitive current in the lamp is a necessary prerequisite to starting of the lamps now available.[34]

The two methods used are called preheat ("hot") starting and instant ("cold") starting. The usual sequences are:

Preheat starting: (a) A heating current is passed through the electrodes and electrons are ejected from the electrodes by thermionic emission. (b) Upon the application of a transient (600–1,200 volts) provided by the ballast and timed by a manual or automatic starting switch, electrons will flow through the tube, ionize the gases, and initiate a mercury vapor discharge.

Instant starting: (a) By the application of a high open circuit voltage (400–3,000 volts depending on the type of lamp and electrode) electrons are ejected by field emission from the electrodes. (b) Electrons will flow through the tube, ionize the gases, and initiate a mercury vapor discharge.

The high-voltage transient induced by rapid dissipation of the ballast magnetic field upon separation of the contacts of the starter switches

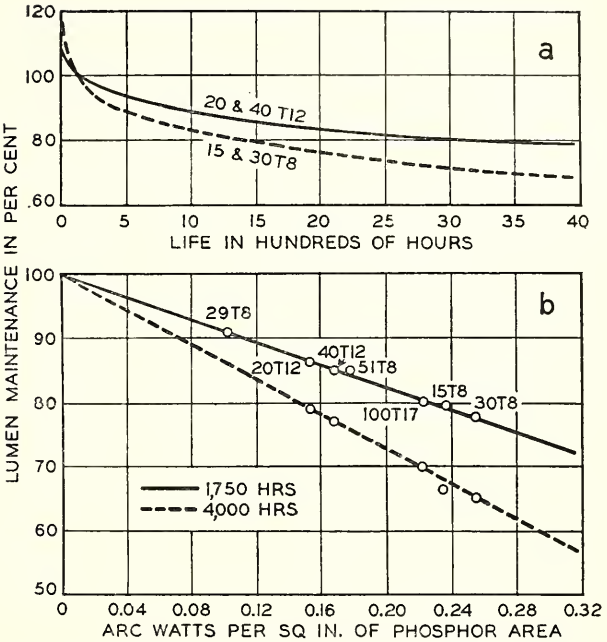


FIG. 6-39 *a*. Lumen maintenance curves for typical T-8 and T-12 lamps. *b*. The reduction in the lumen output of typical fluorescent lamps which accompanies the operation of the lamps is related directly to the incident radiant power density (arc watts per square inch) on the phosphor surface.

used with preheat-starting filament (hot) cathode lamps is sufficient to initiate a glow discharge in a properly preheated and normally operable lamp of this type. The high open-circuit voltage of ballasts designed for instant-starting, cylindrical (cold) cathodes is sufficient to cause the glow discharge without preheating. Humidity ordinarily has no practical effect on the starting of the preheat and the cylindrical cathode lamps.

In the case of filament cathode lamps designed for instant starting at the 400 to 800-volts open circuit provided by "shock-type" ballasts, it is necessary to provide some means of counteracting the effect of high humidity on the capacitive lamp-ground current which initiates the necessary glow discharge under low humidity conditions. Some manufacturers coat the outside of the bulb of this type of lamp with a transparent, nonwetting material; others apply a narrow conducting strip along the bulb. A conducting plate such as a metal reflector near the lamp appears to be advantageous in some cases.[34]

Miscellaneous Fluorescent Lamp Characteristics.

Stroboscopic effect. As indicated in Table 6-11, it is characteristic of light sources operated on alternating current that there is some light output variation of magnitude dependent on the cyclic variations of the current (lower frequency-greater variation). With incandescent lamps this is generally negligible since the filament retains enough heat to compensate for the variation of current throughout each cycle. With fluorescent lamps, the carry-over of light depends on the phosphorescent qualities of the coating. This characteristic of the phosphors varies considerably.

Table 6-11. Approximate Stroboscopic Effect of Fluorescent Lamps, Operated on 60-Cycle Circuits*

Daylight	55	Green	20
White	35	Pink	20
Daylight (two-lamp auxiliary)	25	Red	10
White (two-lamp auxiliary)	16	40-watt filament lamp	13
Blue	90	100-watt filament lamp	5
Gold	25		

* Per cent deviation from mean light output.

Two-lamp, lead-lag ballasts which are available for both hot and cold cathode types reduce this stroboscopic effect to a point where in ordinary two-lamp applications it is negligible. However, it may be an important consideration where moving objects are viewed or where the eye itself is moving rapidly. Further reductions may be made by three-phase operation of three adjacent lamps or pairs of lamps.

Radio interference. The mercury arc in a fluorescent lamp as well as other discharge sources causes a sparking action at the electrodes which emits low-power radio waves. These waves may be picked up and amplified by near-by radios and cause a buzzing noise to be superimposed on the music or speech from the broadcasting station. The sound usually is more noticeable between stations on the dial but may be heard over the entire broadcast band.

To ascertain if the fluorescent lamps are causing radio interference, tune the radio to a point where the interference is most pronounced, and then turn off the fluorescent luminaires. If the noise persists, it is from some source other than the fluorescent lamps. However, if the noise stops, it probably is caused by radio-frequency emission from the fluorescent lamps or auxiliaries. If the radio aerial must remain within about 10 feet of fluorescent lamps, the interference can usually be reduced by performing the following operations: (1) connect the aerial to the radio by means of a shielded lead-in wire with the shield grounded, or install a "doublet"-type aerial with twisted pair leads; (2) provide a good radio-frequency ground for the radio; (3) place the aerial itself out of bulb and line radiation range; (4) use an outside aerial to provide a strong radio signal.

Circuits and auxiliary equipment for fluorescent lamps.

Present types of fluorescent lamps must be operated on circuits which include current control reactance in series with the lamp. High open-circuit voltage or a high transient voltage must be provided by the circuit in order to start a lamp.

As shown in Fig. 6-32, this auxiliary equipment consumes power and therefore reduces the over-all lumen-per-watt rating below that based on the power consumed by the lamp alone.

The high open-circuit voltage associated with cylindrical (cold) cathode, instant-starting fluorescent lamps makes it possible to control the light output of this type by varying the current. The light output of these lamps may be "dimmed" smoothly down to about 10 to 15 per cent of the maximum.

High voltage may also constitute a safety hazard and various protective devices are used to prevent people from coming in contact with an open circuit.

Power factor correction for fluorescent-lamp ballasts. Inherent characteristics of leakage reactance transformers result in a low power factor.

The true watts of a low-power-factor transformer are approximately the same as the true watts of the high-power-factor type when connected to the same load. The low-power-factor type of transformer draws more current from the power supply, and, therefore, larger supply conductors are necessary than when using high-power-factor-type transformers. Some public utilities supplying power have established in their rate schedules penalty clauses for low-power-factor installations and bonus clauses for high-power-factor installations. The use of high-power-factor transformers permits greater loads to be carried by existing wiring systems.

Typical power-factor-corrected circuits for preheat-starting lamps are shown in Fig. 6-40*a*(1) and (2).

The power factor of existing instant-starting ballast installations for cylindrical (cold) cathode lamps can be corrected to the desired value by use of condensers connected across the primary supply lines between the primary switch and the load (Fig. 6-40, b). The use of a capacitor transformer as in circuit 2 of Fig. 6-40 b), usually is less expensive, as the effect of condenser capacity varies as the square of the voltage applied across its terminals. The capacitor transformer is of "auto"-type construction with extended winding depending on the voltage rating of the condenser.

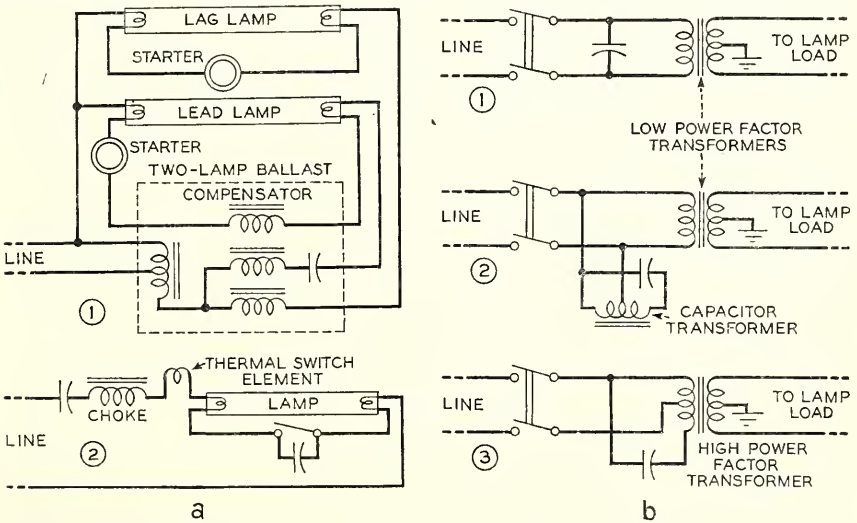


FIG. 6-40. Typical power factor correction methods: a. Preheat-starting, filament-cathode lamp circuits ① two-lamp ballast with integral condenser; ② single-lamp ballast with condenser. b. Instant starting cylindrical (cold) cathode lamp circuits; ① condenser; ② capacitor transformer; ③ integral condenser in high power factor transformer.

For example, if a condenser capacity of 16 microfarads is required at 110 volts to correct the power factor to a desired value, the capacity can be reduced to 1 microfarad if 440 volts are applied to the condenser terminals. In new installations high-power-factor transformers should be used. This type is shown in circuit 3 of Fig. 6-40,*b*. The primary winding is extended to a value three to six times the input voltage in order to reduce the condenser capacity.

Preheat starting switches.

In a preheat circuit a switch completes a series circuit so a preheat current can flow through the filament cathodes and heat them, and then breaks this circuit so that the resulting transient voltage from the ballast will start the lamp. The ballast permits a limited current to flow through the cathode filaments, which heats the filaments slowly (usually this takes about a second, as compared with 0.0001 second for heating an incandescent lamp filament). Several seconds may elapse before the entire starting operation is complete. A small (0.006 microfarad) condenser across the switch contacts aids in starting but is primarily useful in shunting out line-lead harmonics which may cause radio interference. The simplest concept of a starter switch is a push button which may be held down for a second or two and released. This type is used for desk-type fluorescent luminaires and also with the two-14-watt lamp circuit. The starters described below represent several designs for accomplishing the operation automatically.

Thermal-switch starter. On starting, the ballast, starter heating element, and lamp cathodes are in series across the line. The contacts of thermal-switch starters normally are closed, as shown in Fig. 6-41*a*. The cathode preheating current also heats the bimetallic strip in the starter, causing the contacts to open. The induced voltage then starts the lamp, the normal operating current holding the thermal switch open thereafter.

Thermal-switch starters consume some power ($\frac{1}{2}$ to $1\frac{1}{2}$ watts) during lamp operation, but their design ensures more positive starting by providing: (1) an adequate preheating period, (2) a higher induced starting voltage, and (3) characteristics inherently less susceptible to line-voltage variations. For these reasons they give best all-around performance of 40-watt lamps, being especially useful under adverse conditions such as direct-current operation, low ambient temperature, and varying voltage.

Glow switch starter. The glass bulb shown in Fig. 6-41*b* is filled with neon, helium, or argon, depending on the lamp size. On starting, when there is practically no voltage drop at the ballast, the voltage at the starter is sufficient to produce a glow discharge between the U-shaped bimetallic strip and the fixed contact or center electrode. The heat from the glow activates the bimetallic strip, the contacts close, and cathode preheating begins. This short-circuits the glow discharge, so the bimetal cools and in a very short time the contacts open. The transient voltage thus induced is sufficient to start the lamp. During normal operation, there is not enough voltage across the lamp to produce further starter glow so the contacts remain open and the starter consumes no power.

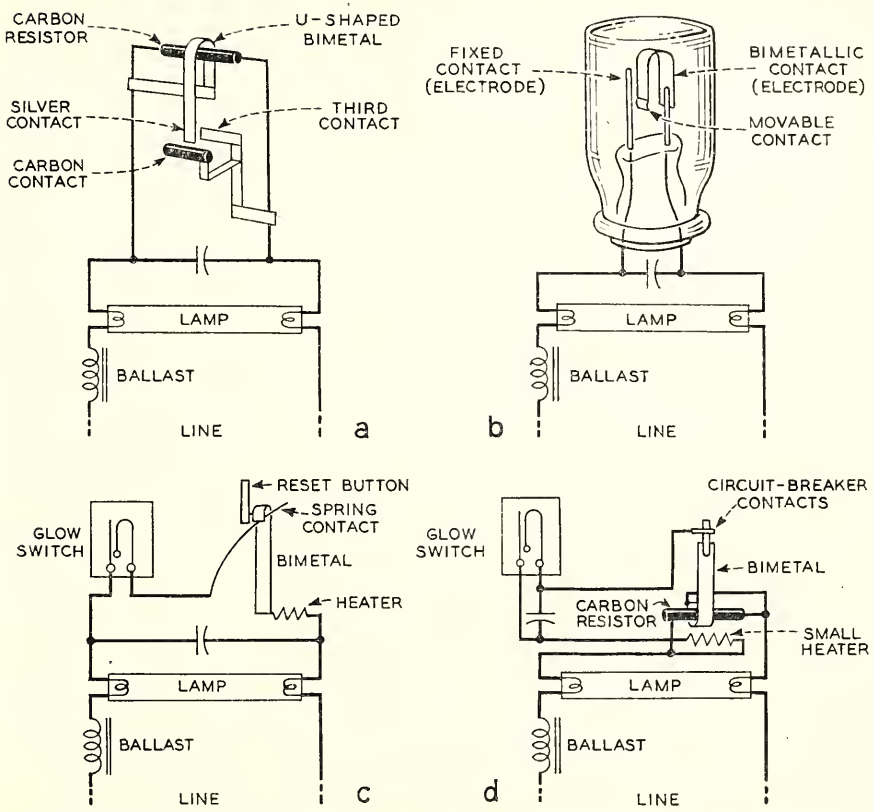


FIG. 6-41. Starter switches for preheat cathode circuits: (a) thermal type; (b) glow switch type; (c) manual reset type; (d) automatic reset type.

Lockout starter. This starter, which may be either manual or automatic, is an improved glow switch which prevents the annoying blinking caused by repeated attempts to start a deactivated lamp. This type of starter should last for ten or more lamp renewals.

Manual reset starter. This starter, shown in Fig. 6-41*c*, uses the glow-switch principle and, during normal starting, the switch functions in the manner that has been described. This starter has a wire-coil heater element actuating a bimetallic arm which serves as a latch to hold a second switch in a normal closed position. When a lamp is deactivated or will not start for some reason after repeated attempts and blinks on and off, enough heat is developed (after 15 to 20 seconds at rated line voltage) by the intermittent flow of cathode preheating current so that the latch pulls away and releases a spring-operated switch in the starter circuit. At the time the lamp is replaced, the starter may be reset to operating position by pushing down on the reset button.

Automatic reset starter. This type, shown in Fig. 6-41*d*, consists of a glow switch and additional bimetallic element which automatically opens

the glow switch circuit after a reasonable number of unsuccessful attempts to start a deactivated lamp.

A low-resistance heater in series with the glow switch carries the starting current. As the switch attempts to start a deactivated lamp, the heater gradually heats the bimetal and opens the lockout contacts in the glow switch circuit. Open circuit voltage then exists across a resistor which is connected in parallel across these elements. This resistor consumes negligible power (less than one watt), but produces sufficient heat to hold the lockout contacts open. When the deactivated lamp is replaced, the starter automatically resets to its normal position, ready to function again.

Typical circuits

Several auxiliary circuits for operating fluorescent lamps in multiple and in series are shown in Fig. 6-42.

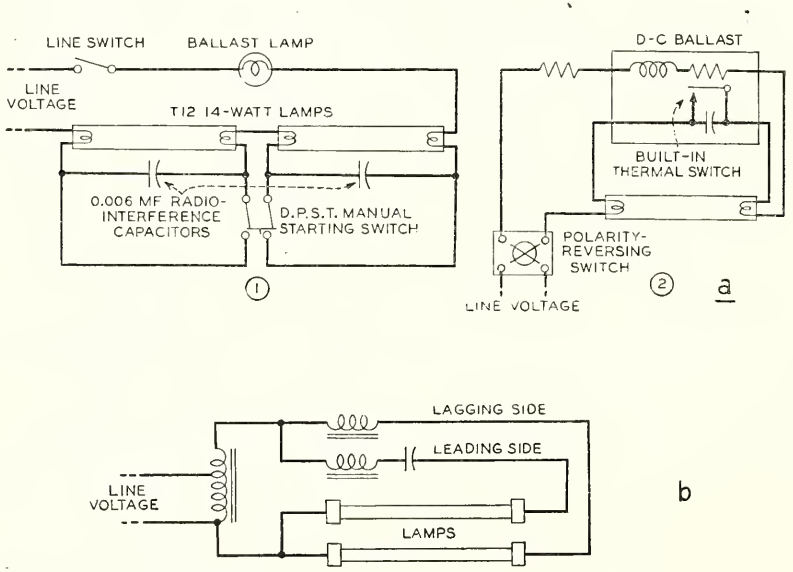
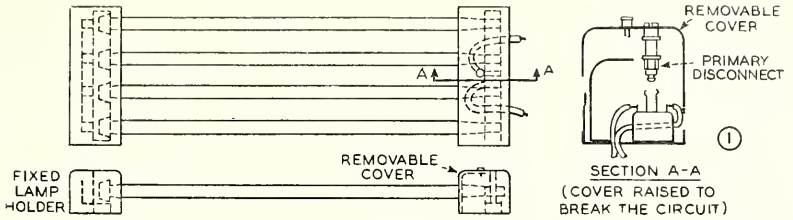
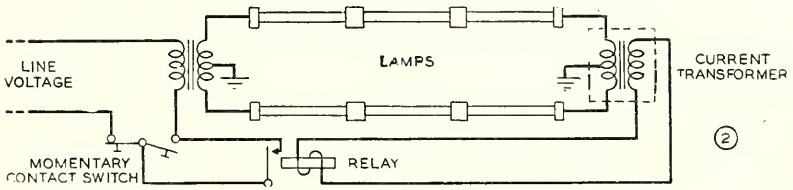
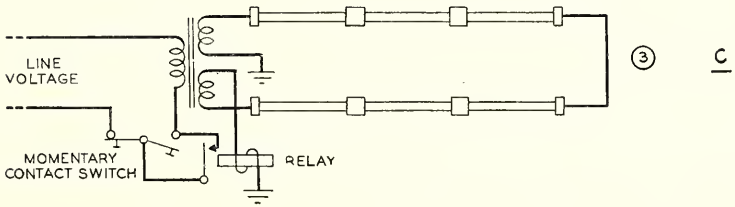
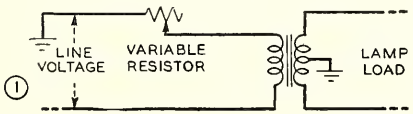


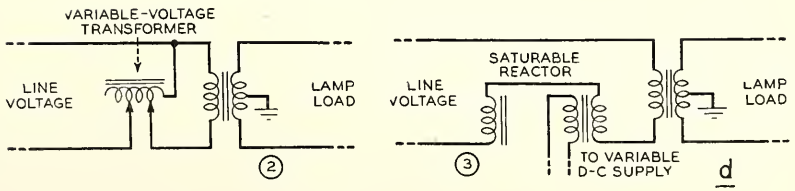
FIG. 6-42. Typical fluorescent lamp circuits:[21] a. Circuits for preheat-starting, filament-cathode lamps: (1) series circuit for 14-watt lamps with incandescent lamp resistance ballast and manual starting switch; (2) ballast for use on direct-current circuits. b. Two-lamp circuit for instant-start lamps on which the lamps are operated out of phase to minimize stroboscopic effect. c. Safety circuits for instant-start, cylindrical (cold) cathode lamp operation in interiors: (1) four-lamp, two-ballast circuit in which removal of a lamp-base cover disconnects transformer primary; (2) circuit developed by the Detroit Board of Education for use where lamps are subject to breakage; (3) circuit for use in refrigerated showcases. d. Dimming-circuits for series-connected, cylindrical (cold) cathode lamps: (1) variable resistance; (2) variable voltage transformer; (3) saturable reactor.


REMOVABLE COVER
PRIMARY DISCONNECT
A
A
REMOVABLE COVER
FIXED LAMP HOLDER
SECTION A-A
(COVER RAISED TO BREAK THE CIRCUIT)
1


LINE VOLTAGE
LAMPS
CURRENT TRANSFORMER
MOMENTARY CONTACT SWITCH
RELAY
2


LINE VOLTAGE
MOMENTARY CONTACT SWITCH
RELAY
3
C


LINE VOLTAGE
VARIABLE RESISTOR
LAMP LOAD
1


VARIABLE-VOLTAGE TRANSFORMER
LINE VOLTAGE
LAMP LOAD
2
SATURABLE REACTOR
LINE VOLTAGE
LAMP LOAD
TO VARIABLE D-C SUPPLY
3
d

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SECTION 7

LIGHT CONTROL

Once light has been produced by combustion, incandescence, gaseous discharge, fluorescence, or other means, the problem of primary importance is its control. Light sources, such as flames or arcs, or incandescent, electric discharge, or fluorescent lamps, rarely are found to have the inherent characteristics of candlepower distribution, brightness, and color suited to direct application without control or modification. Also, certain uncontrollable application conditions such as smoke, fog, condensation of moisture, collection of dust, grease, and so forth may alter the characteristics of either lamp or luminaire in service.

Modification of lamp characteristics or compensation for uncontrollable application conditions may be provided in a number of ways, all of which are examples of one or a combination of the following phenomena (which will be taken up in the order given here):

Reflection.	Polarization.	Diffusion.
Refraction.	Interference.	Absorption.
	Diffraction.	

Light Path Phenomena

Since most design problems may be solved by assuming light to be represented by bundles of rays which travel along straight lines, this convention is used in this handbook. A few examples are given in small type of the methods used to explain the phenomena which take place as light is transmitted or reflected at the interface between mediums having different optical properties. These examples utilize the concept that light emanates from a source in the form of "wave fronts." The behavior of these wave fronts can be described graphically and used to explain various phenomena, involving principally a change in the direction of wave propagation.[1, 2, 3]

Wave motion may be represented graphically as shown in Fig. 7-1, the plot of the function

$$Y = a \sin 2\pi \left(\frac{t}{T} - \frac{x}{\lambda} \right)$$

where

Y = displacement of particles from point P on the wave path (at time t)
a = amplitude of the wave
T = period of oscillation (time)
x = distance along the wave path from origin to point P
λ = wavelength

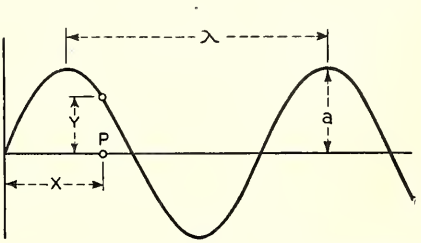


FIG. 7-1. Graphical representation of a plane wave.

Phase differences between motions at points 0 and P are equal to $2\pi X/\lambda$; when X/λ is a whole number, the motions are in phase.[1]

NOTE: References are listed at the end of each section.

Superposition of wave trains is illustrated by the three curves in Fig. 7-2. Wave fronts associated with waves emanating from a source of energy are the locus lines (see Fig. 7-3) of points in the wave train that move in phase. Wave fronts are perpendicular to their direction of propagation.

Huygens' principle is the concept that each point in the wave front (primary wave) is itself the source of secondary waves or wavelets. This principle may be applied, as in Fig. 7-4, to demonstrate how the front progresses along its path.

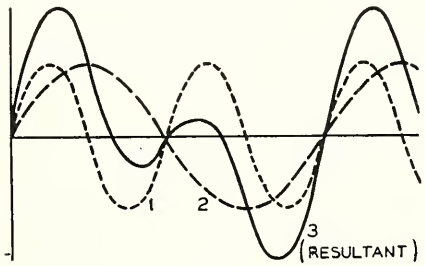


FIG. 7-2. The superposition of the amplitudes of two individual wave trains (1 and 2) traveling in the same direction along one path results in a third disturbance (3) moving along the same path in that direction.

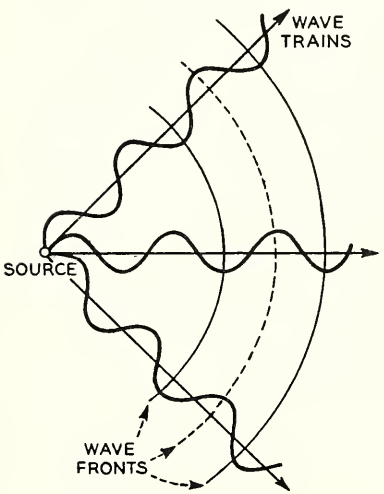


FIG. 7-3. Wave fronts are the loci of points the motion of which is in phase.

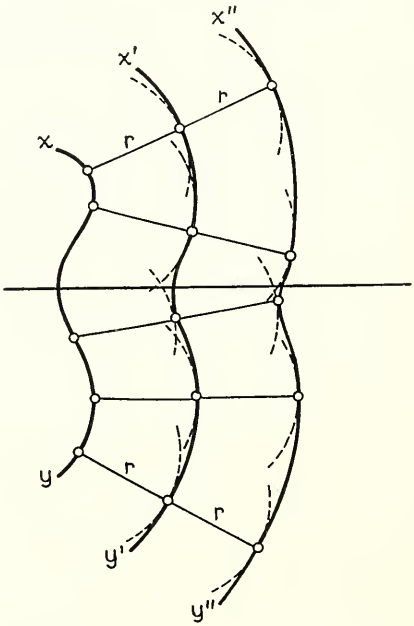


FIG. 7-4. New wave fronts may be constructed (Huygens' principle) by describing arcs of equal radius with centers at each point in the known front and drawing the curve (or surface) tangent to these arcs (or spherical segments).

Reflection

By reflection a medium redirects incident light beams. Reflection may be specular, spread, diffuse, or compound, and selective or nonselective. Reflection from the front of a glass plate is called "first"-surface reflection and that from the back "second"-surface reflection. Refraction, diffusion, and absorption by supporting mediums are avoided in first-surface reflectors.[4]

1. Specular Reflection

If a surface is polished (microscopically smooth) it reflects specularly, that is, the angle between the reflected ray and the normal to the surface will equal the angle between the incident ray and the normal, Fig. 7-5(*a*.)

If two or more rays are reflected, these may form a virtual, erect, or inverted image of the source. A lateral reversal of the image occurs when odd numbers of plane mirrors are used, as in Fig. 7-5(*b*). The image is left-handed for an even number, right-handed for an odd number.

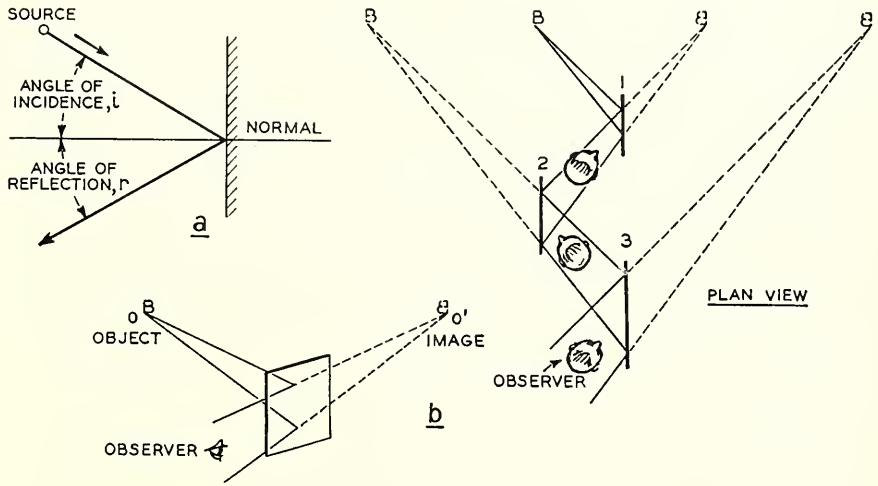


FIG. 7-5. (a) The law of reflection states that the angle of incidence i = angle of reflection r. (b) A lateral reversal of the image accompanies reflections from an odd number of plane mirrors.

Examples of specular reflectors

1. Polished and electroplated metals* and first-surface silvered glass or plastic mirrors: Inside-aluminized, sealed-beam lamps and reflecting telescopes use first-surface reflectors in which the incident light strikes the thin metal reflecting surface without passing through the glass, as shown

* Silver, gold, or copper for example.

in Fig. 7-6(*b*). The function of the latter is simply to provide a rigid support for the reflecting surface.

Applications: where accurate control is desired.

Maintenance: smooth surface, easily cleaned. Materials such as polished silver must be protected from the atmosphere. Others such as anodized aluminum may be exposed to ordinary atmospheres without serious depreciation.

Light reflected from the upper surface of a glass plate, as in Fig. 7-6(*a*) and (*c*), also is an example of first-surface reflection. As shown in Fig. 7-8, less than 10 per cent of the incident light is reflected at the first surface unless it strikes the surface at wide angles from the normal.

The sheen of silk and the shine from smooth or coated paper are images of light sources reflected in the first surface. Images of light sources and other objects seen in opaque polished glass store fronts and table tops, counter tops, and store windows are formed by first-surface reflections.

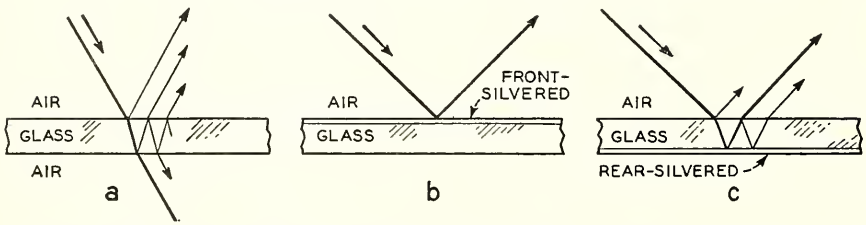


FIG. 7-6. Reflections from (a) clear plate glass and (b) from front and (c) rear silvered mirrors.

2. Rear-surface mirrors. Some light (the quantity depending on the incident angle) is reflected by the first surface. The rest goes through to the silvered backing and is reflected out through the glass, as shown in Fig. 7-6(*c*), parallel to the ray reflected by the first surface (except for a small portion that is reflected internally at the first surface and emerges eventually as a third ray). This multiple reflection is of negligible effect in luminaires. The household mirror is one example of back-silvered, second-surface reflectors.

3. One-way vision or half-silvered mirrors. These mirrors are coated with an extremely thin layer of silver or aluminum so that they are semi-transparent. When viewed against a comparatively dark background they appear to be ordinary mirrors, but it is possible to look through them into a brightly lighted area. The view is dim, and likely to be tinted with the characteristic color of light transmitted by the finely divided metal of the coating.

Applications: where accurate control is desired but sharp images are not essential.

Maintenance: the silvering is protected by glass; the smooth surface facilitates cleaning.

Reflection of a plane wave from a specular plane surface. Figure 7-7 indicates the angle of incidence i is equal to the angle of reflection r. Applying Huygens' principle, the construction is explained as follows:

1. Consider the line LL' as the plane specular reflecting surface.

2. Let the line WW' in position ① represent the plane wave front approaching the surface in the direction indicated by the arrows perpendicular to the front (commonly known as rays).

3. Assume that at some time t the wave front, except for the presence of the reflecting surface, would have progressed to position ②.

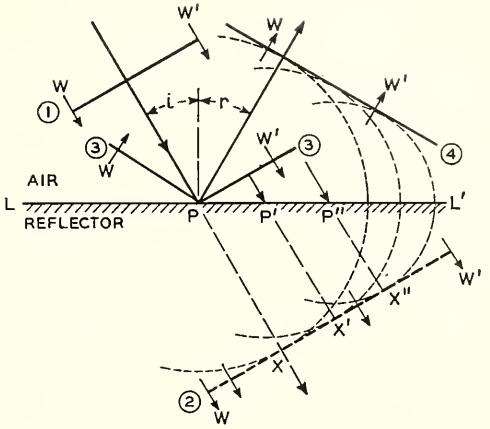


FIG. 7-7. Reflection of a plane wave at a plane (specular) surface showing Huygens' construction of the new wave front.

4. However, if the location of the front ③ is considered at some intermediate instant, it is found contact has been made with the surface at point P, from which a Huygens' wavelet has emanated at the same velocity as that of the primary wave at the instant of contact.

5. Therefore, if an arc is described with center at P and radius equal to PX, the actual front of the new wavelet at time t has been established. It is a hemisphere on the air side of the reflector.

6. By describing additional arcs at succeeding points of contact P' and P'' with radii $P'X'$ and $P''X''$ (only two are necessary in the case of the plane wave) it is possible, by constructing the tangent to these arcs, to determine the actual position ④ of the primary wave front WW' after reflection.

In this manner the principle may be applied equally well to a reflection of plane or spherical waves from either plane or figured surfaces, though the construction is more complex.[3] Refraction may be explained a similar manner.

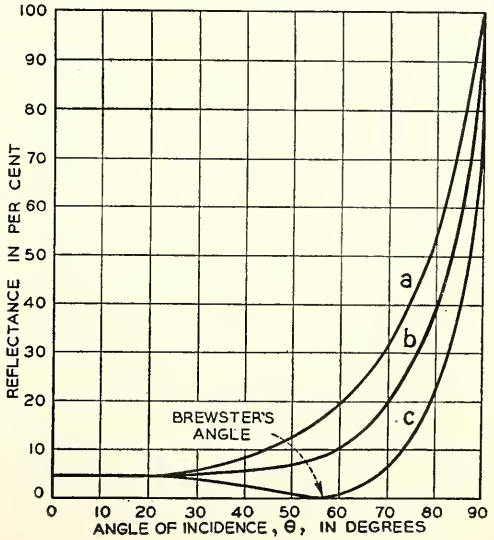


FIG. 7-8. Effect of angle of incidence and state of polarization on per cent of light reflected at an air-glass* surface: (a) Incident light polarized in the plane of incidence. (b) Nonpolarized light. (c) Incident light polarized in plane perpendicular to plane of incidence.

* For spectacle crown glass, $n = 1.523$.

2. Spread Reflection

If a surface is figured in any way (corrugated, deeply etched, or hammered) it spreads any rays it reflects, that is, a *pencil* of incident rays is spread out into a *cone* of reflected rays, as shown in Fig. 7-9(*b*).

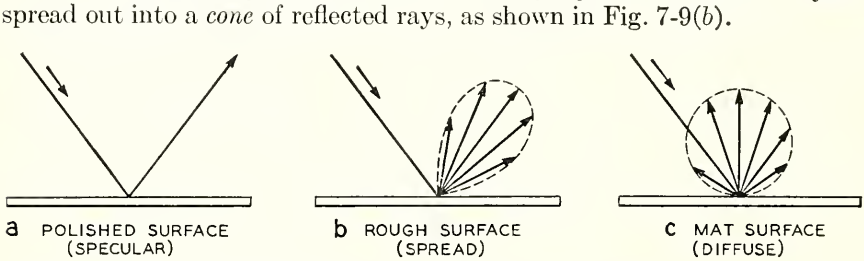


FIG. 7-9. The type of reflection varies with different surfaces: (*a*) polished surface (specular); (*b*) rough surface (spread); (*c*) mat surface (diffuse).

Spread reflectors. Depolished metals and similar surfaces reflect individual rays at slightly different angles but all in the same general direction.

Applications: where smooth beam and moderate control is required.

Maintenance: collect dust and dirt more rapidly than smooth surface. Chemical cleaners often used.

Corrugated, brushed, dimpled, etched, or pebbled surfaces consist of small specular surfaces in irregular planes. Brushing the surface spreads the image at right angles to the brushing. Pebbled, lightly hammered, or etched surfaces produce a random patch of highlights.

Applications: where beams free from striations and filament images are required; widely used for sparkling displays.

Maintenance: ease of cleaning depends on the shape and size of the indentations.

3. Diffuse Reflection

If a material has a rough surface or is composed of minute crystals or pigment particles, the reflection is diffuse. Each single ray falling on an infinitesimal particle obeys the laws of reflection, but, as the surfaces of the particles are in different planes, they reflect the light at many angles.

With perfectly diffuse reflection (microscopic roughness: surface particle diameters less than wavelength of light—seldom attained in practice) the reflected light distribution is independent of the angle at which the light strikes the surface. No matter what this angle may be, the maximum intensity of the light reflected is normal to the surface and the light is spread throughout an angle of 180 degrees. If the reflected beams are plotted, as in Fig. 7-9(*c*), they will fill a circle (in three dimensions a sphere). This spherical distribution characteristic of perfectly diffuse reflected light is determined by the cosine law. The intensity (I_θ) at an angle (θ) from the normal is proportional to the cosine of that angle:

$$I_\theta = I_{90^\circ} \cos \theta$$

Diffuse reflectors. Flat paints and other mat finishes and materials reflect at all angles and exhibit little directional control.

Applications: where wide distribution of light is desired.

Maintenance: cleaning is often difficult since surfaces which approach microscopic roughness are likely to collect and hold dirt.

4. Compound Reflection

Most common materials are compound reflectors and exhibit all three reflection components (specular, spread, and diffuse). In some, one or two components predominate, as shown in Fig. 7-10. Specular and narrowly spread reflection (usually surface reflection) cause the "sheen" on etched or embossed aluminum, textiles, semigloss paint, snow fields, and so forth.

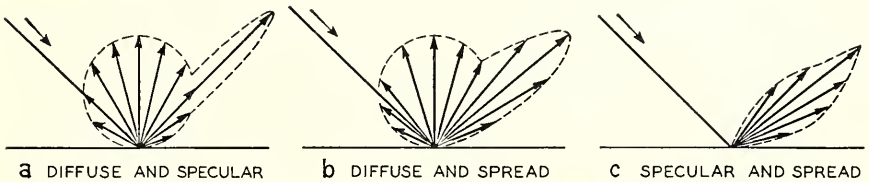


FIG. 7-10. Examples of compound reflection: (*a*) diffuse and specular; (*b*) diffuse and spread; (*c*) specular and spread.

Diffuse-specular reflectors. Porcelain enamel, glossy paints, and enamels and other surfaces with a shiny transparent finish over a mat base exhibit no directional control except for the specularly reflected ray that is shown in Fig. 7-10(*a*), which usually amounts to from 5 to 15 per cent of the incident light.

Applications: diffusing reflectors. Bright source images make such finishes undesirable for walls and ceilings.

Maintenance: glossy finish results in permanency of the reflecting surface and easy cleaning.

Refraction

A change in the velocity of light (speed of propagation, not frequency) occurs when a ray leaves one material and enters another of greater or less physical density. The speed will be reduced if the medium entered is more dense and increased if it is less dense.[3]

Except when light enters at an angle normal to the surface of a medium of different density, the change in speed always is accompanied by a bending of the light from its original path at the point of entrance, as shown in Fig. 7-11. This is known as refraction. The degree of bending depends on the relative densities of the two substances, on the wavelength of the light, and on the angle of incidence, being greater for large differences in density than for small. The light is bent toward the normal to the surface when it enters a more dense medium and away from the normal when it enters a less dense material. One result of refraction is that the

ray path followed is that with the highest *average* velocity in any given case. *Fermat's principle* states that the total path will be the one which takes the least time to traverse.

When light is transmitted from one medium to another, each single ray follows the law of refraction. When a pencil of rays strikes or enters a new medium the pencil may be broken up and scattered in many directions because of irregularities of the surface, such as fine cracks, mold marks, scratches, or changes in contour, or because of foreign deposits of dirt, grease, or moisture.

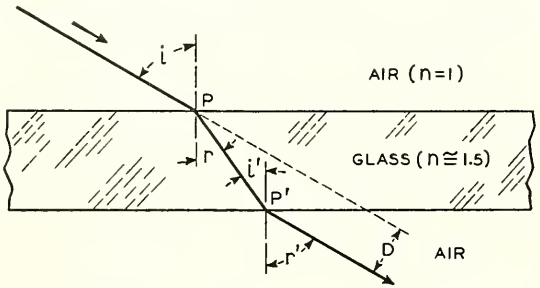


FIG. 7-11. Refraction of light rays at a plane surface causes bending of the incident rays and displacement of the emergent rays. The bending and displacement is greater when the ray goes from a light to a dense medium than when it goes from a dense to a light medium.

The law of refraction (Snell's law) is expressed:

$$n_1 \sin i = n_2 \sin r$$

where n_1 = the index of refraction of the first medium
i = the angle the incident light ray forms with the normal to the surface
n_2 = the index of refraction of the second medium
r = the angle the refracted light ray forms with the normal to the surface

When the first medium is air, of which the index of refraction usually is assumed to be 1 (correct to three decimal places but actually the index for a *vacuum*) the formula becomes:

$$\sin i = n_2 \sin r$$

The two interfaces of the glass plate shown in Fig. 7-11 are parallel and therefore the entering and emerging rays also are parallel. The rays are displaced from each other because of refraction.

Examples of refraction. A common example of refraction is the apparent bending of a straw at the point where it enters the water in a drinking glass. Although the straw is straight, light rays coming from that part of the straw under water are refracted when they pass from the water into the air and appear to come from higher points. Objects seen through window glass sometimes appear distorted as a result of the nonuniform thickness and flatness characteristic of window glass. These irregularities cause irregular refraction of transmitted rays and distortion of the images of objects at which the rays originate.

Prismatic light directors, such as shown in Fig. 7-12(*a*) and (*b*), may be designed to provide a variety of light distributions for illumination purposes.

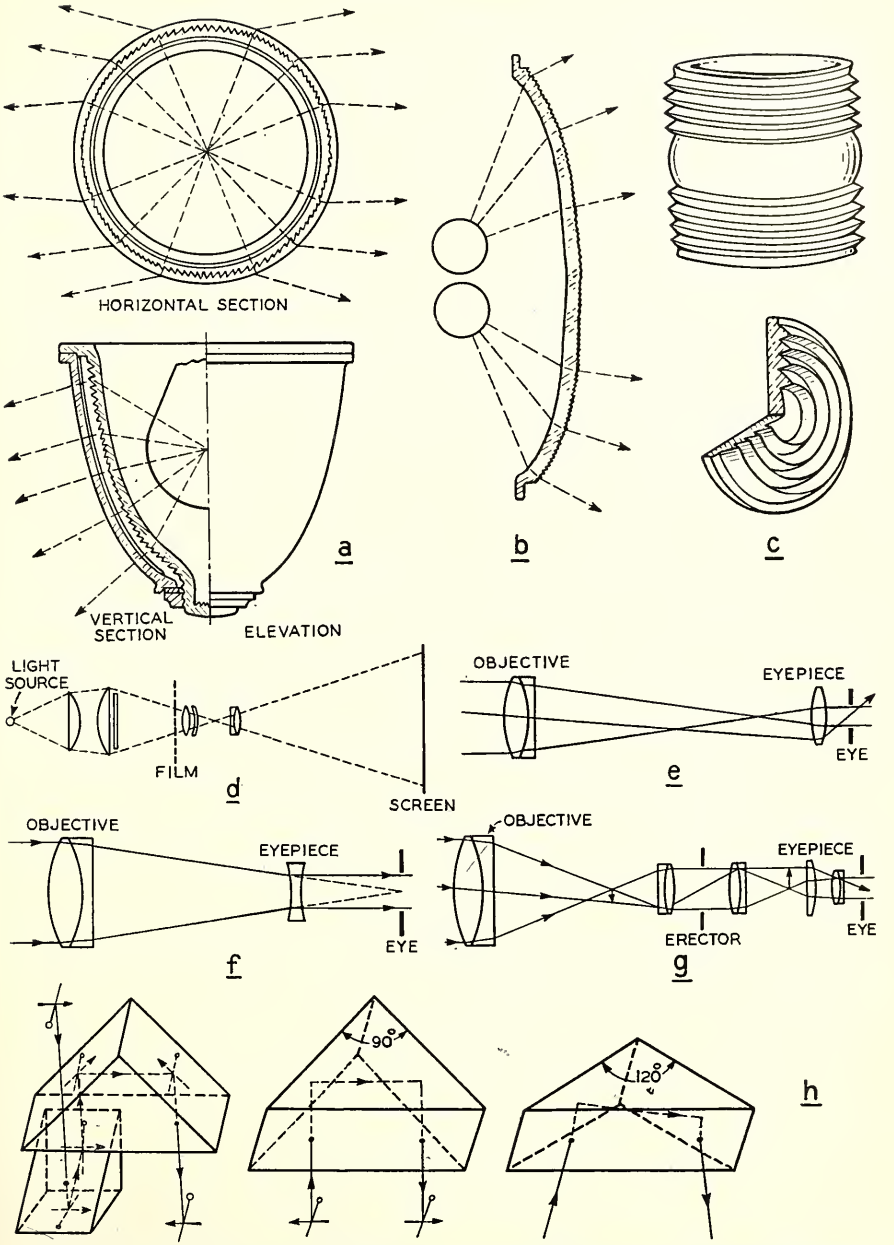


FIG. 7-12. Optical systems utilizing the refractive properties of prisms and lenses: (*a*) Street-lighting unit in which the inner piece controls the light in vertical directions (concentrating the rays into a narrow beam at about 75 degrees from the vertical) and the outer piece redirects the light in the horizontal plane. The result is a "two-way" type of candlepower distribution. (*b*) Prismatic lens for fluorescent lamp luminaire intercepts as much light as possible, redirecting part from the glare zone to more useful directions. (*c*) Cylindrical and flat Fresnel lenses. (*d*) Lantern slide projector. (*e*) Astronomical telescope. (*f*) Galilean telescope. (*g*) Terrestrial telescope. (*h*) Reflecting prisms.

Lens systems controlling light by refraction are used in automobile headlights, in beacon, floodlight, and spotlight Fresnel lenses, in downlights and in picture projectors, and in telescopes, field glasses, microscopes, and so forth,[4] as shown in Fig. 7-12.

Compensation for abnormal vision is provided by spectacles, which utilize refractive properties of lenses to change the direction of light entering the eye.

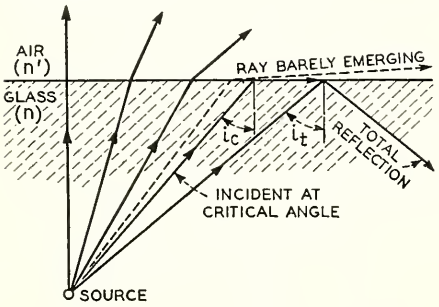


FIG. 7-13. Total reflection occurs when $\sin r = 1$. The critical angle i_c varies with the mediums.

Total reflection of a light ray at a surface of a transmitting medium occurs when the angle of incidence exceeds a certain value at which $\sin r$ becomes equal to 1. If the index of refraction of the first medium (n_1) is greater than that of the second medium (n_2), $\sin r$ will become unity when $\sin i$ is equal to n_2/n_1. At angles of incidence greater than this critical angle (i_c) the incident rays are reflected totally, as in Fig. 7-13.

In air when light strikes normally a piece of ordinary glass ($n_2/n_1 = 0.66$) about 4 per cent is reflected from the upper surface and about 3 or 4 per cent from the lower surface. Approximately 85 to 90 per cent of the light is transmitted and 2 to 8 per cent absorbed. The proportion of reflected light increases slowly as the angle of incidence is increased. In air total reflection occurs whenever $\sin i$ is greater than 0.66, that is, for all angles of incidence greater than 41.8 degrees (air→glass). Both edge lighting and efficient light transmittance through rods and tubes are functions of total reflection.[5] See Fig. 7-8 b.

Prisms. Many devices use total internal reflection by prisms for redirection, inversion, and erection of light beams. Performance quality depends on flatness of reflecting surfaces, accuracy of prism angles, elimination of back surface dirt in optical contact with the surface, and elimination (in manufacture) of prismatic error.

Dispersion of light by a prism. Consideration of Snell's law:

$$n_2 = \frac{\sin i}{\sin r} = \frac{\text{Velocity of light in air}}{\text{Velocity in prism}}$$

suggests, since the velocity of light is a function of the index of refraction of the mediums involved and also of wavelength, that the exit path from a prism will be different for each wavelength of incident light and for each angle of incidence. (See Fig. 7-14.) This orderly separation of incident light into its spectrum of component wavelengths is called dispersion.

The angle of minimum deviation D is related to the prism angle A and to the index of refraction n_2, as follows:

$$n_2 = \frac{\sin\left(\frac{A+D}{2}\right)}{\sin\frac{A}{2}}$$

however, if the prism angle is small, the approximations

$$n_2 = \frac{D}{A} + 1, \text{ or}$$

$$D = (n_2 - 1)A$$

are reasonably accurate. See Fig. 7-14.

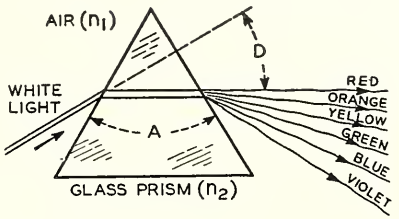


FIG. 7-14. White light is dispersed into its component colors by refraction when passed through a prism. Angle D is the angle of deviation.

Refractors and Refractor Materials

Glass, transparent plastics, and quartz are used in the manufacture of refractive devices.

Refracting prisms. The degree of bending of light at each prism surface is a function of the refractive indices of the two mediums and the prism angle. Light can be directed accurately within certain angles by having the proper angle between the prism faces.

In the design of refracting equipment the same general considerations of proper flux distribution hold good as for the design of reflectors. Following Snell's law of refraction the prism angles can be computed to provide the proper deviation of the light rays from the source. For most commercially available transparent material like glass or plastics, the index of refraction used lies between 1.5 and 1.6.

Often, by proper placement of the prisms, it is possible to limit the prismatic structure to only one surface of the refractor, leaving the other surface entirely smooth for easy maintenance. The number and the sizes of prisms used are governed by several considerations. Among them are ease of manufacture, convenient maintenance of lighting equipment in service, and so forth. A large number of small prisms may suffer from prism rounding in actual manufacture; on the other hand, small prisms produce greater accuracy of light control.[4]

Applications: headlight lenses, refracting luminaires, optical systems of scientific instruments. See Fig. 7-12(*a*), (*b*), (*c*) and (*h*).

Ribbed and prismed surfaces can be designed to spread rays in one plane or scatter them in all directions.

Applications: luminaires, footlight lenses, luminous elements, glass blocks, windows and skylights.

Maintenance: smooth surface, easy to clean if prisms are not too small.

Reflecting prisms reflect light internally, as shown in Fig. 7-12(*h*).

Applications: luminaires, retrodirective markers.

Maintenance: moisture, moist dirt, and grease in optical contact with surfaces reduce reflection; smooth glass permits easy cleaning but must be cleaned on both surfaces (front and rear).

Fresnel lenses. Excessive weight and cost of glass in large lenses used in illumination equipment can be reduced considerably by a method developed by Fresnel. Several variations are used, as shown in Fig. 7-12(*c*). The use of lens surfaces parallel to those replaced (shown by the dotted line) brings about a great reduction in thickness. The optical action is approximately the same. Although outside prisms are slightly more efficient, they are likely to collect more dust. Therefore, prismatic faces often are formed on the inside.

Positive lenses form convergent beams and real inverted images as in Fig. 7-15(*a*). *Negative lenses* form divergent beams and virtual, inverted images as in Fig. 7-15(*b*).

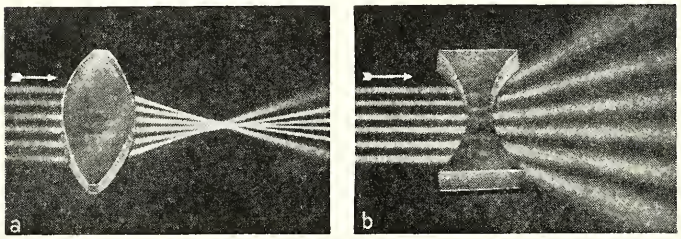


FIG. 7-15. Ray path traces through lenses: (*a*) positive, (*b*) negative.

Lens aberrations. There are, in all, seven principal lens aberrations: spherical, coma, axial and lateral achromatism, astigmatism, curvature and distortion. Usually they are of little importance in lenses used in common types of lighting equipment. In telescopic objectives and the like (small angular fields), the most important are spherical aberration, coma, and axial achromatism, which are illustrated in Fig. 7-16(*a*), (*b*) and (*c*). In such systems as photographic objectives (wide angular fields), astigmatism, curvature of field, and distortion also are important. These are shown in Fig. 7-16 (*d*) and (*e*). In modern telescopic and photographic lenses astigmatism and curvature usually are eliminated for all practical purposes and the lenses are likely to be complex. The simpler the lens system, the more difficult is the correction of the aberrations.[6]

Transmittance and Transmitting Materials

Transmittance is a characteristic exhibited to some degree by many materials: glass, plastics, textiles, crystals, and so forth. The luminous transmittance T of a material is the ratio of the total emitted light to the total incident light; it is affected by reflections at each surface of the material, as explained above, and by absorption within the material.

Bouger's or Lambert's law. Absorption in a clear transmitting medium is an exponential function of the thickness of the medium traversed:

$$I = I_0 t^x$$

where I = intensity of transmitted light.
I_0 = intensity of light entering the medium *after surface reflection.*
t = transmittance of unit thickness.
x = thickness of sample traversed.

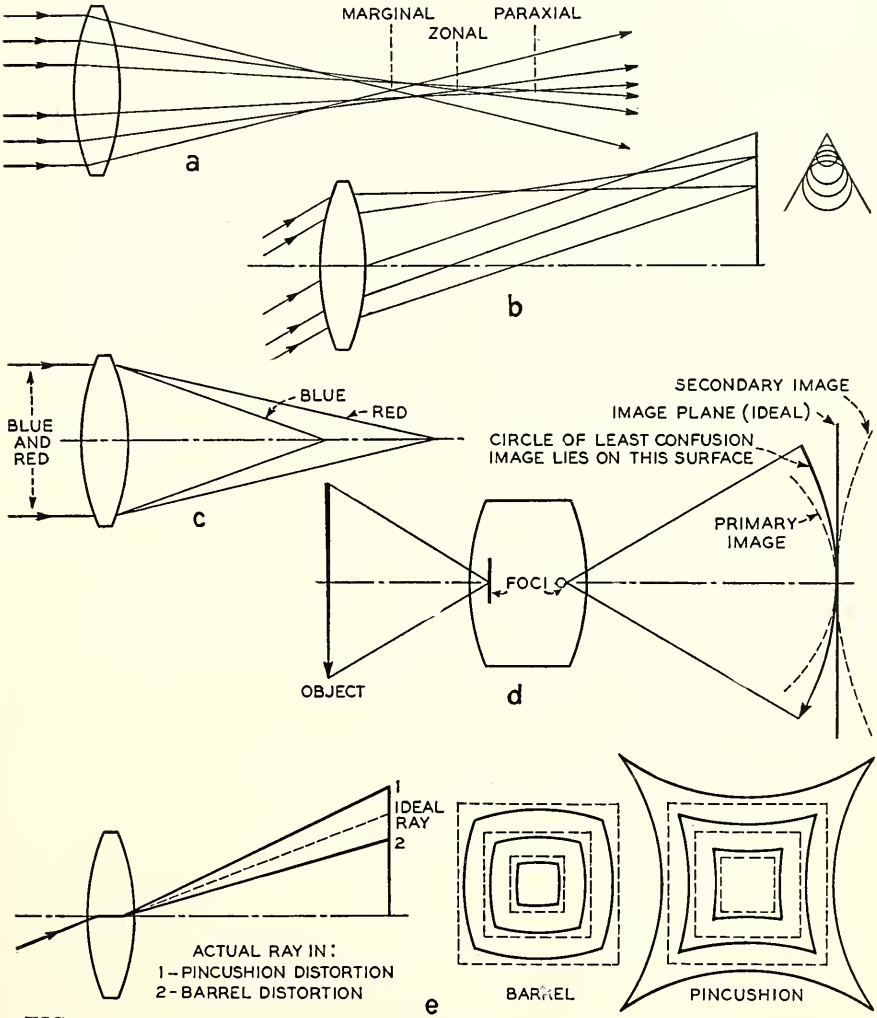


FIG. 7-16. Lens aberrations: (*a*) Spherical aberration: conversion at different focal points of parallel rays at varying distances from the axis of a lens. (*b*) Coma: difference in the lateral magnification of rays passing through different zones of a lens. (*c*) Chromatism: a difference in focal length for rays of different wavelengths. (*d*). Astigmatism and curvature: existence in two parallel planes of two mutually perpendicular line foci and a curved image plane. (*e*) Distortion: a difference in the magnification of rays passing through a lens at different angles.

Optical density (D) is the common logarithm of the reciprocal of transmittance (T): $D = \log_{10}\left(\frac{1}{T}\right)$.

Spread transmittance materials offer a wide range of textures, both when lighted from behind and when not.

Applications: for brightness control as in frosted lamp bulbs, in luminous elements where accents of brilliance and sparkle are desired, and in moderately uniform brightness luminaire-enclosing globes. Care should be used in placing lamps to avoid glare and spotty appearance.

Figure 7-17(a) shows a beam of light striking the smooth side of a piece of etched glass. In Fig. 7-17(b) the frosted side is toward the source, a condition that with many ground or otherwise roughened glasses results in appreciably higher transmittance.

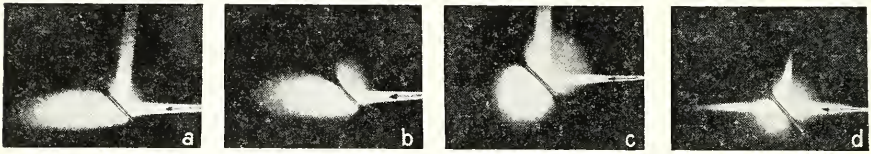


FIG. 7-17. (a) Spread transmittance of light incident on *smooth* surface of figured, etched, ground, or hammered glass samples. (b) Spread transmittance of light incident on *rough* surface of the same samples. (c) Diffuse transmittance of light incident on solid opal and flashed opal glass, white plastic or marble sheet. (d) Mixed transmittance through opalescent glass.

Maintenance: for outdoor use the rough surface usually must be enclosed to avoid excessive dirt collection. Etched surfaces are difficult to keep clean; smooth surfaces are easy to clean.

Diffusing materials scatter light in all directions, as shown in Fig. 7-17(c). White, opal, and prismatic glassware are used widely.

Applications: luminous areas where uniform brightness is desired.

Maintenance: smooth surfaces minimize dust collection and permit easy cleaning.

Mixed transmittance materials. Mixed transmittance is a result of a spectrally selective diffusion characteristic exhibited by certain materials such as fine opal glass, which permits the plane transmission of certain colors (wavelengths) while diffusing other wave-lengths. This characteristic in glass varies greatly, depending on such factors as its heat treatment, composition, and thickness and the wavelengths of the incident light.

Louvers. Louvers are panels or baffles mounted in such a position that light transmitted by them is confined in a particular direction. They frequently are used to reduce the "spill" from a luminaire and thus to increase the attainable control. The most effective louvers have a small cross section (as viewed from the area to be lighted), are opaque, and have a flat black surface. However, louvers may be and often are translucent or finished in light colors. Typical louvers are shown in Fig. 7-18.

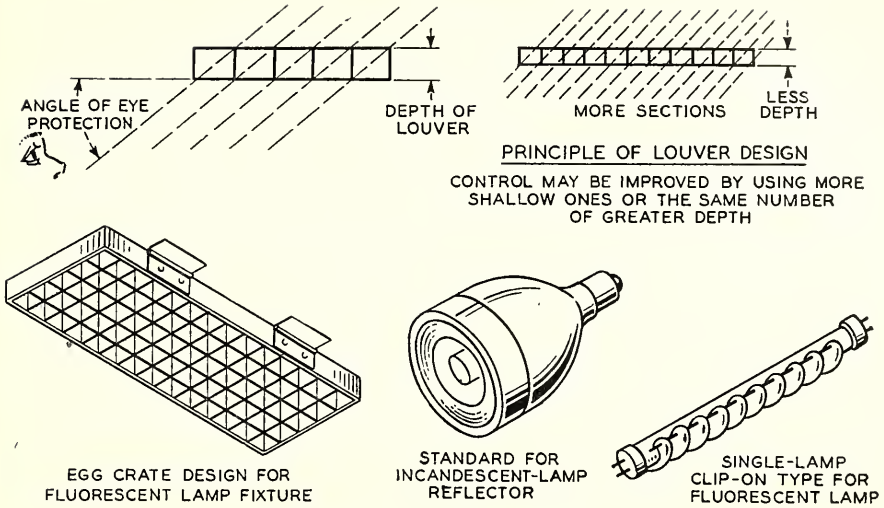


FIG. 7-18. Typical louver designs.

Polarization

Light waves emitted by common sources are oriented at all angles in planes at right angles to the direction of the beam emitted from a source. As they pass through certain substances or are reflected from certain surfaces at particular angles, vibrations in some directions are absorbed more than are those in other directions. Light which vibrates more strongly in certain directions is said to be polarized.

The action of a taut rope fixed at one end and agitated at the other is analogous to that of a polarized light wave. As indicated in Fig. 7-19(*a*), when the end of the rope moves in a vertical line, a knot at any point along the rope will move in a parallel line. When the end of the rope moves through a circle, the knot will traverse a circle; and if the end revolves in

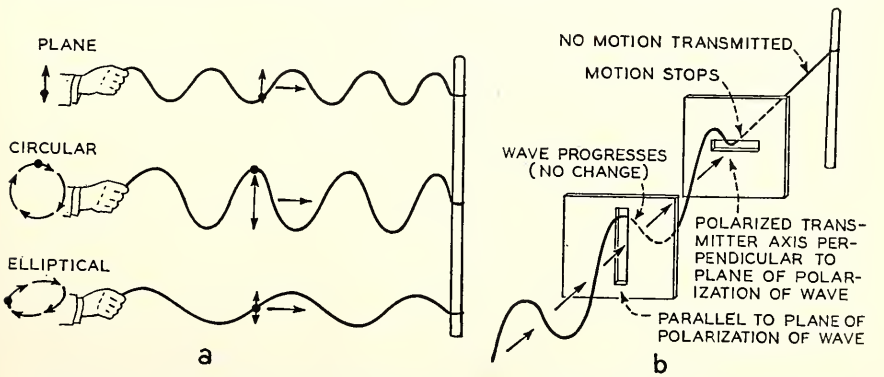


FIG. 7-19. (*a*) Wave motion shows various types of polarization. (*b*) Polarized transmitters pass only that component of polarized wave motion which has its axis parallel to their plane of polarization.

an elliptical path, so will the knot. The movement of the knot in each case is in a plane perpendicular to the direction of propagation of the wave.

If a pair of plates pierced by narrow slots, through which the rope is threaded, is introduced, as in Fig. 7-19(*b*), and the slots are oriented at right angles to each other, a most important characteristic of a polarized wave is revealed: *a polarized transmitting plate passes only that component of the incident wave that is parallel to its axis of polarization.* A polarized light transmitter introduced in a light path will pass only those disturbance components in planes parallel to its axis of polarization.[1, 2]

Examples of polarization. Skylight, particularly from the section opposite the sun, is somewhat polarized. Light from any source specularly reflected from glossy surfaces, such as glass, glossy paint, varnish, bodies of water, and so forth, also is partially polarized in a plane parallel to the reflecting surface. A polarizing transmitting material mounted in sun glasses with the plane of polarization normal to that of the reflecting surface absorbs the polarized specular reflection, permitting only the component of the unpolarized light parallel to the plane of polarization to pass through.

Desk luminaires emitting polarized light have been produced[7] and it has been suggested that the glare of automobile headlights may be reduced by polarizing their beams and then viewing the oncoming polarized headlights through a polarizing screen.[8] A screen in front of the driver with its axis oriented at 90 degrees with the beam would absorb the direct light of the headlight beam but would permit viewing the road, since polarized light which falls on the road is depolarized by reflection.

Spectral transmission and polarizing characteristics of two polarizers are given in Fig. 7-20.

Polarization may occur when light is reflected. For certain angles of incidence, polarization by reflection at surfaces of transmitting mediums may be nearly complete. This may be explained as follows:

In Fig. 7-21 nonpolarized radiation is incident on the glass at *P*. Since light is a

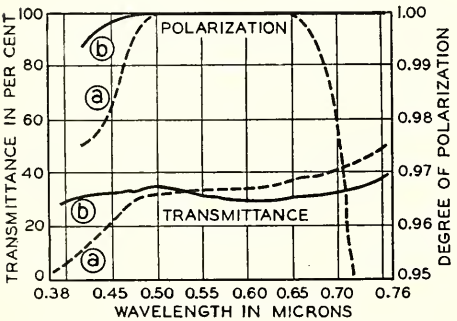


FIG. 7-20. Characteristics of commercial polarizers: (*a*) Early type comprised of iodo-quinine sulphate crystals imbedded in a plastic (trade name: Polaroid *J* film). (*b*) Modern polyvinyl alcohol molecular polarizer (trade name: Polaroid *H* film).

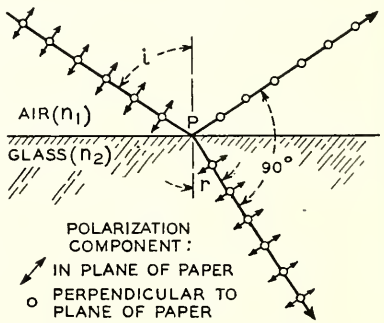


FIG. 7-21. Polarization by reflection at a glass-air surface is at a maximum when the sum of the angle of incidence *i* plus the angle of refraction *r* equals 90 degrees. (See text.)

transverse wave motion the disturbance at each point along the path can be resolved into two rectangular components, perpendicular to and in the same plane of the paper, indicated respectively by the dots and arrows. At the point of contact some of the incident light will be reflected, some refracted, some absorbed; and some of that absorbed will be re-emitted in the reflected ray. Since the motion is transverse, if the angle between reflected and refracted rays is 90 degrees, none of the disturbance components parallel to the plane of incidence of the refracted rays can be re-emitted in the reflected ray, and only radiation polarized in a plane parallel to the surface is reflected.

The *polarizing angle* (sometimes called Brewster's angle) at which polarization will be most nearly complete, occurs when the sum of the angles of incidence i and refraction r equals 90 degrees. It is determined by the relationship known as Brewster's law:

$$n_2 = \tan i$$

where

n_2 = index of refraction for the reflecting medium
i = angle of incidence

At all other angles of incidence the reflected ray will include polarization components in other planes. Figure 7-8 shows the variation in reflectance which occurs at various angles of incidence for both polarized and nonpolarized light at an air-glass surface.

Interference

When two light waves come together at different phases of their vibration, they combine to make up a single wave whose amplitude equals the sum of the amplitudes of the two. This interference phenomenon is utilized to increase luminous transmittance,[6] and for extremely accurate thickness measurements in machine shops.[2] Interference also is the cause of the diffraction pattern which is sometimes seen around a pin hole or at the edge of a shadow cast by the sharp edge of an opaque screen and of irridescence in bubbles, oil slicks and other thin films.[9]

Low reflectance films. These films are applied to surfaces to reduce reflectance, increase transmittance, and consequently improve contrast relationships. The effect of these films on the reflectance of single and multisurface optical systems is shown in Fig. 7-22. Films a quarter wave length thick with an index of refraction between that of the medium surrounding the glass and that of the glass are used. The hardest and most permanent films are those of magnesium fluoride condensed on the trans-

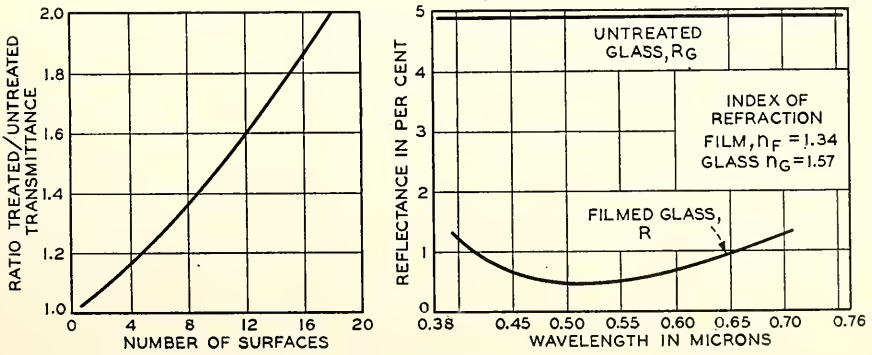


FIG. 7-22. Reduction in reflection losses by low reflection films.

mitting surface after thermal evaporation in vacuum, and protected by a thin layer of zircon or quartz applied in the same manner.[10]

The normal, uncoated, 4-per-cent reflection at air-glass surfaces may be reduced to less than 1 per cent at each filmed surface. This reduction is the result of cancelling interference between the waves reflected at the air → film and film → glass surfaces.

Diffraction

When a wave front is obstructed partially, as by the edge of a reflector or a louver, the shadow cast by the reflector or louver may be sharp or "soft," depending on the geometrical relationship and size of the source, reflector, and illuminated surface. This phenomenon, which is seldom of any consequence in ordinary lighting, is known as diffraction.[1,2]

Diffusion

Diffusion is the breaking up of a beam of light and the spreading of its rays in many directions by irregular reflection from microscopic foreign particles within a transmitting medium, or from microscopic irregularities of a reflecting surface. One almost perfectly diffuse reflecting surface is a freshly-cut, magnesium-oxide surface. Opal glass also is a good diffusor, when etched on one side. Perfect diffusion seldom is attained in practice but sometimes is assumed in calculations in order to simplify the mathematics.

Absorption

Absorption occurs when a light beam enters a smoky atmosphere, or a piece of glass or plastic or meets a dense body. Part of the incident light is reflected from particle to particle within the body until its energy has been absorbed and converted into heat. Because of the nonuniform size of the particles (relative to the wavelength of light) and because of their spectral reflectance, the absorption characteristics of practically all materials are selective (accompanied by change of color of light).

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SECTION 8

LIGHTING CALCULATIONS

Engineering work in lighting as in all other fields requires the application of mathematical or graphical techniques to the solution of many different types of problems.

At best, cut-and-try methods are inefficient. Often they are inaccurate and expensive. They are not likely to provide the best practical solution of even the most simple problem.

Fortunately, it is possible to solve most lighting application problems without using anything more complicated than addition, subtraction, multiplication, or division. Frequently, some of these operations may be avoided, if it is so desired, by using simple graphs and tables. A number of these time-saving short cuts are included in this section or in the Appendix, and others will be found in the references. It usually is necessary to compromise with accuracy to a certain extent when short-cut methods are used and this should be considered when choosing a method for solving a problem. In many cases, however, the short cuts save a great deal of time and provide reasonably accurate results.

In addition to the methods of solving application problems given in this section, assistance in the solution of design and development problems will be found in the references at the end of the section and in the reference division.

AVERAGE ILLUMINATION

Many present-day interior lighting designs have as their major objective the provision of a certain average maintained general illumination level. Appendix Table A-1, page A-1, includes illumination levels (footcandles) representative of good practice in many commercial, industrial, educational, recreational, and home areas.[1]

The Lumen Method

The method of calculation most frequently used to estimate the number and type of lamps or luminaires, or both, which will maintain a given average illumination level in service in a particular interior is based on the classic experiments of Harrison and Anderson[2] who established a relationship between the candlepower distribution characteristics of luminaires, their mounting height, and the room proportions.

The *required number of lamps* of a particular type will equal the total initial light flux F divided by the rated lumen output of that type.

The *required rated lumen output per lamp*, when the number of lamps is fixed by the desired spacing, type of fixtures, or other consideration, will equal the total initial light flux F divided by the number of lamps.

Note: References are listed at the end of each section.

The relationship may be expressed as the coefficient of utilization, k_u, in the following equations:

$$E_{av} = \frac{F \times k_u \times k_m}{A} \qquad k_u = \frac{E_{av} \times A}{F \times k_m}$$

$$F = \frac{E_{av} \times A}{k_u \times k_m} \qquad k_m = \frac{E_{av} \times A}{F \times k_u}$$

where

E_{av} = average illumination *maintained in service* on a horizontal working plane 30 inches above the floor.* See Table 8-1.

F = total initial light flux from all lamps (lumens)

k_u = coefficient of utilization (a dimensionless ratio)

k_m = maintenance factor which compensates for the in-service reduction in light output of lamps and reflecting surface (dimensionless ratio)

A = floor area (square feet)

* Four per cent less than the absolute illumination. Corresponds approximately with reading of photometer in which test plate error causes readings that are 4 per cent low.

Values obtained using these equations are tabulated in Table 8-1 for various values of k_u, k_n, and A corresponding to a value of F = 1,000 lumens.

Maintenance factor. Allowance must always be made for depreciation of lamps and light control elements below initial or design values so that the desired footcandle levels may be maintained in service.[3] For the most part, filament lamps average in service around 90 per cent of their initial lumen output and fluorescent lamps average around 80 per cent. Dust, grease, and so forth that collect quickly on reflecting surfaces account for another 10 to 20 per cent normal depreciation even with a reasonable cleaning schedule. Therefore, the average illumination maintained in service will, under good conditions, be of the order of 60 to 70 per cent of the initial value, or 0.6–0.7 expressed as the maintenance factor, k_m. In some instances, particularly with direct-lighting luminaires where there is little dust and smoke in the atmosphere, a higher value may be obtained. For open indirect equipment, cove lighting, skylights, and similar types of hard-to-reach and likely-to-be-neglected installations, a considerably lower factor should be assumed as indicated in Table 8-2. This table includes factors for these three conditions:[4]

1. Good maintenance factor—where the atmosphere is free of smoke, dust, and so forth, the luminaires are cleaned frequently, and the lamps are replaced systematically.

2. Medium maintenance factor—where less clean atmospheric conditions exist, the luminaire cleaning is fair, and the lamps are replaced only after burnout.

3. Poor maintenance factor—where the atmosphere is quite dirty and the equipment is poorly maintained.

Table 8-1. Average Maintained Illumination Produced on the Horizontal Working Plane per 1,000 Lamp Lumens* for Various Spacing†, Maintenance, and Utilization Conditions.[20]

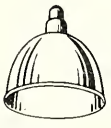
AREA† PER LAMP (SQ FT)	MAINTENANCE FACTOR	COEFFICIENT OF UTILIZATION																	
		0.36	0.38	0.40	0.42	0.44	0.46	0.48	0.50	0.52	0.54	0.56	0.58	0.60	0.62	0.64	0.66	0.68	0.70
10	70	25.2	26.6	28.0	29.4	30.8	32.2	33.6	35.0	36.4	37.8	39.2	40.6	42.0	43.4	44.8	46.2	47.6	49.0
	60	21.6	22.8	24.0	25.2	26.4	27.6	28.8	30.0	31.2	32.4	33.6	34.8	36.0	37.2	38.4	39.6	40.8	42.0
	50	18.0	19.0	20.0	21.0	22.0	23.0	24.0	25.0	26.0	27.0	28.0	29.0	30.0	31.0	32.0	33.0	34.0	35.0
12	70	21.0	22.1	23.3	24.5	25.6	26.8	28.0	29.1	30.3	31.5	32.6	33.8	35.0	36.1	37.3	38.5	39.6	40.8
	60	18.0	19.0	20.0	21.0	22.0	23.0	24.0	25.0	26.0	27.0	28.0	29.0	30.0	31.0	32.0	33.0	34.0	35.0
	50	15.0	15.8	16.6	17.5	18.3	19.2	20.0	20.8	21.6	22.5	23.3	24.1	25.0	25.8	26.6	27.5	28.3	29.1
14	70	18.0	19.0	20.0	21.0	22.0	23.0	24.0	25.0	26.0	27.0	28.0	29.0	30.0	31.0	32.0	33.0	34.0	35.0
	60	15.4	16.2	17.1	18.0	18.8	19.7	20.5	21.4	22.2	23.1	24.0	24.8	25.7	26.5	27.4	28.2	29.1	30.0
	50	12.8	13.5	14.2	15.0	15.7	16.4	17.1	17.8	18.5	19.2	20.0	20.7	21.4	22.1	22.8	23.5	24.2	25.0
16	70	15.7	16.6	17.5	18.3	19.2	20.1	21.0	21.8	22.7	23.6	24.5	25.3	26.2	27.1	28.0	28.8	29.7	30.6
	60	13.5	14.2	15.0	15.7	16.5	17.2	18.0	18.7	19.5	20.2	21.0	21.7	22.5	23.2	24.0	24.7	25.5	26.2
	50	11.2	11.8	12.5	13.1	13.7	14.3	15.0	15.6	16.2	16.8	17.5	18.1	18.7	19.3	20.0	20.6	21.2	21.8
18	70	14.0	14.7	15.5	16.3	17.1	17.8	18.6	19.4	20.2	21.0	21.7	22.5	23.3	24.1	24.8	25.6	26.4	27.2
	60	12.0	12.6	13.3	14.0	14.6	15.3	16.0	16.6	17.3	18.0	18.6	19.3	20.0	20.6	21.3	22.0	22.6	23.3
	50	10.0	10.5	11.1	11.6	12.2	12.7	13.3	13.8	14.4	15.0	15.5	16.1	16.6	17.2	17.7	18.3	18.8	19.4
20	70	12.6	13.3	14.0	14.7	15.4	16.1	16.8	17.5	18.2	18.9	19.6	20.3	21.0	21.7	22.4	23.1	23.8	24.5
	60	10.8	11.4	12.0	12.6	13.2	13.8	14.4	15.0	15.6	16.2	16.8	17.4	18.0	18.6	19.2	19.8	20.4	21.0
	50	9.00	9.50	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0	17.5
30	70	8.40	8.86	9.32	9.80	10.0	10.7	11.2	11.6	12.1	12.6	13.0	13.5	14.0	14.4	14.9	15.4	15.8	16.3
	60	7.20	7.60	8.00	8.40	8.80	9.20	9.60	10.0	10.4	10.8	11.2	11.6	12.0	12.4	12.8	13.2	13.6	14.0
	50	6.00	6.33	6.66	7.00	7.33	7.66	8.00	8.33	8.66	9.00	9.33	9.66	10.0	10.3	10.6	11.0	11.3	11.6
40	70	6.30	6.65	7.00	7.30	7.70	8.05	8.40	8.75	9.10	9.45	9.80	10.1	10.5	10.8	11.2	11.5	11.9	12.2
	60	5.40	5.70	6.00	6.30	6.60	6.90	7.20	7.50	7.80	8.10	8.40	8.70	9.00	9.30	9.60	9.90	10.2	10.5
	50	4.50	4.75	5.00	5.25	5.50	5.75	6.00	6.25	6.50	6.75	7.00	7.25	7.50	7.75	8.00	8.25	8.50	8.75
50	70	5.02	5.32	5.60	5.88	6.16	6.44	6.72	7.00	7.28	7.56	7.84	8.12	8.40	8.68	8.96	9.24	9.52	9.80
	60	4.32	4.56	4.80	5.04	5.28	5.52	5.76	6.00	6.24	6.48	6.72	6.96	7.20	7.44	7.68	7.92	8.16	8.40
	50	3.60	3.80	4.00	4.20	4.40	4.60	4.80	5.00	5.20	5.40	5.60	5.80	6.00	6.20	6.40	6.60	6.80	7.00
60	70	4.20	4.43	4.66	4.90	5.13	5.36	5.60	5.83	6.06	6.30	6.53	6.76	7.00	7.23	7.46	7.70	7.93	8.16
	60	3.60	3.80	4.00	4.20	4.40	4.60	4.80	5.00	5.20	5.40	5.60	5.80	6.00	6.20	6.40	6.60	6.80	7.00
	50	3.00	3.16	3.33	3.50	3.66	3.83	4.00	4.16	4.33	4.50	4.66	4.83	5.00	5.16	5.33	5.50	5.66	5.83
70	70	3.60	3.80	4.00	4.20	4.40	4.60	4.80	5.00	5.20	5.40	5.60	5.80	6.00	6.20	6.40	6.60	6.80	7.00
	60	3.08	3.25	3.43	3.60	3.77	3.94	4.11	4.28	4.45	4.63	4.80	4.97	5.14	5.31	5.48	5.66	5.83	6.00
	50	2.57	2.71	2.85	3.00	3.14	3.28	3.43	3.57	3.71	3.85	4.00	4.14	4.28	4.43	4.57	4.71	4.85	5.00
80	70	3.15	3.34	3.50	3.67	3.85	4.02	4.20	4.37	4.55	4.72	4.90	5.07	5.25	5.42	5.60	5.77	5.95	6.12
	60	2.70	2.85	3.00	3.15	3.30	3.45	3.60	3.75	3.90	4.05	4.20	4.35	4.50	4.65	4.80	4.95	5.10	5.25
	50	2.25	2.37	2.50	2.62	2.75	2.87	3.00	3.12	3.25	3.37	3.50	3.62	3.75	3.87	4.00	4.12	4.25	4.37
90	70	2.80	2.95	3.12	3.26	3.42	3.57	3.73	3.88	4.04	4.20	4.35	4.51	4.66	4.82	4.97	5.13	5.28	5.44
	60	2.40	2.53	2.66	2.80	2.93	3.06	3.20	3.33	3.46	3.60	3.73	3.86	4.00	4.13	4.26	4.40	4.53	4.66
	50	2.00	2.11	2.22	2.33	2.44	2.55	2.66	2.77	2.88	3.00	3.11	3.22	3.33	3.44	3.55	3.66	3.77	3.88
100	70	2.52	2.66	2.80	2.94	3.08	3.22	3.36	3.50	3.64	3.78	3.92	4.06	4.20	4.34	4.48	4.62	4.76	4.90
	60	2.16	2.28	2.40	2.52	2.64	2.76	2.88	3.00	3.12	3.24	3.36	3.48	3.60	3.72	3.84	3.96	4.08	4.20
	50	1.80	1.90	2.00	2.10	2.20	2.30	2.40	2.50	2.60	2.70	2.80	2.90	3.00	3.10	3.20	3.30	3.40	3.50
150	70	1.68	1.77	1.86	1.96	2.05	2.14	2.24	2.33	2.42	2.52	2.61	2.70	2.80	2.89	2.98	3.08	3.17	3.26
	60	1.44	1.52	1.60	1.68	1.76	1.84	1.90	1.98	2.06	2.14	2.22	2.30	2.38	2.46	2.54	2.62	2.70	2.78
	50	1.20	1.26	1.33	1.40	1.46	1.53	1.60	1.66	1.73	1.80	1.86	1.93	2.00	2.06	2.13	2.20	2.26	2.33
200	70	1.26	1.33	1.40	1.47	1.54	1.61	1.68	1.75	1.82	1.89	1.96	2.03	2.10	2.17	2.24	2.31	2.38	2.45
	60	1.08	1.14	1.20	1.26	1.32	1.38	1.44	1.50	1.56	1.62	1.68	1.74	1.80	1.86	1.92	1.98	2.04	2.10
	50	.900	.950	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75

* If lamp output is 2,000 lumens multiply tabulated values by $\frac{2,000}{1,000}$.

If lamp output is 500 lumens multiply tabulated values by $\frac{500}{1,000}$. Table applies to all types of lamps.

† If area per luminaire or per room rather than area per lamp is used, divide tabulated values by no. of lamps per luminaire or no. of lamps per room respectively.

Table 8-2. Coefficients of Utilization, Efficiencies,* Distribution Characteristics,† and Maintenance Factors‡ for Typical Luminaires Computed for a Wide Range of Installation Conditions.§[4]

LUMINAIRE	DISTRIBUTION	SPACING and Maintenance Factor	Ceiling...	70%			50%			30%	
			Walls.....	50%	30%	10%	50%	30%	10%	30%	10%
			Room Index	COEFFICIENT OF UTILIZATION							
 Direct: R.L.M. Dome Reflector	0 / 79	Spacing not to exceed 1 x MH MF G .75 M .65 P .55	J	.37	.31	.27	.36	.31	.27	.31	.27
			I	.45	.41	.38	.45	.40	.37	.40	.37
			H	.49	.45	.42	.49	.45	.42	.45	.42
			G	.53	.49	.46	.53	.49	.46	.48	.46
			F	.56	.53	.49	.55	.52	.49	.51	.49
			E	.61	.58	.55	.60	.57	.55	.56	.55
			D	.66	.63	.60	.64	.62	.60	.61	.60
			C	.67	.65	.62	.66	.64	.62	.63	.61
			B	.71	.68	.66	.69	.67	.65	.66	.64
			A	.72	.70	.67	.71	.68	.67	.67	.66
 Direct: R.L.M. Deep-Bowl Reflector	0 / 70	Spacing not to exceed: 1 x MH MF G .75 M .65 P .55	J	.35	.31	.28	.34	.31	.28	.30	.28
			I	.43	.39	.37	.42	.39	.37	.39	.37
			H	.46	.44	.42	.46	.44	.42	.43	.42
			G	.50	.47	.45	.49	.47	.45	.46	.45
			F	.53	.50	.47	.51	.49	.47	.49	.47
			E	.56	.54	.51	.56	.54	.51	.53	.51
			D	.61	.58	.56	.59	.57	.56	.56	.56
			C	.62	.60	.57	.61	.58	.57	.58	.56
			B	.64	.62	.61	.63	.61	.60	.60	.59
			A	.65	.63	.61	.64	.62	.61	.61	.60
 Direct: Aluminum High-Bay Reflector, Concentrating	0 / 75	Spacing not to exceed 0.6 x MH MF G .75 M .60 P .40	J	.43	.40	.39	.42	.40	.39	.40	.38
			I	.51	.50	.49	.50	.49	.48	.49	.46
			H	.55	.54	.53	.54	.53	.52	.53	.52
			G	.59	.58	.57	.58	.56	.55	.56	.55
			F	.61	.60	.58	.59	.58	.58	.58	.57
			E	.64	.63	.62	.63	.62	.61	.61	.60
			D	.68	.65	.64	.66	.65	.64	.64	.63
			C	.69	.67	.65	.67	.66	.64	.64	.64
			B	.70	.68	.67	.68	.67	.66	.66	.65
			A	.71	.70	.68	.69	.67	.67	.67	.66
 Direct: Aluminum High-Bay Reflector, Medium Spread	0 / 75	Spacing not to exceed 1 x MH MF G .75 M .65 P .50	J	.40	.36	.34	.39	.36	.34	.36	.33
			I	.48	.45	.43	.47	.44	.43	.44	.42
			H	.52	.50	.48	.51	.49	.47	.49	.47
			G	.55	.53	.52	.55	.52	.51	.52	.51
			F	.58	.56	.53	.56	.55	.53	.55	.53
			E	.62	.60	.58	.61	.59	.57	.58	.57
			D	.66	.63	.61	.64	.62	.61	.62	.61
			C	.67	.65	.62	.66	.64	.62	.63	.62
			B	.69	.67	.66	.67	.65	.64	.65	.64
			A	.70	.68	.67	.69	.67	.65	.66	.64

* 0 / 79 — 0 per cent of initial lamp lumens in upper hemisphere. 0 + 79 = initial luminaire efficiency. 79 per cent of initial lamp lumens in lower hemisphere.

† I.C.I. classifications: D = direct; SD = semidirect; G = general diffuse; SI = semi-indirect; I = indirect.

‡ MF = Maintenance factors based on the following percentages of initial lamp lumens emitted at 70-percent rated life: 40-watt fluorescent 0.76, 100-watt fluorescent 0.72, incandescent 0.85, mercury 0.84.
G = Good. M = Medium. P = Poor.

Note: Consider cleaning schedule, ceiling and wall reflectances, type of work, heating, and ventilation as well as type of lamp and luminaire when choosing factor. Good conditions are seldom encountered.

§ MH = Mounting height above floor.
CH = Ceiling height above floor.
Room indices for rooms of different proportions are given in Table 8-3.

Table 8-2. Continued

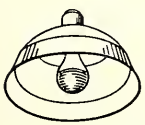
LUMINAIRE	DISTRIBUTION	SPACING and Maintenance Factor	Ceiling...	70%			50%			30%	
			Walls.....	50%	30%	10%	50%	30%	10%	30%	10%
			Room Index	COEFFICIENT OF UTILIZATION							
 Direct: Concentrating or Medium, Heavy-Duty Type	0 ↑ — ↓ 70	Spacing not to exceed Conc. 0.5 x MH Med. 0.8 x MH MF G .80 M .72 P .65	J	.40	.38	.36	.39	.38	.36	.38	.36
			I	.48	.46	.45	.47	.46	.45	.45	.43
			H	.52	.51	.50	.51	.50	.49	.50	.48
			G	.55	.54	.53	.54	.53	.52	.53	.51
			F	.57	.56	.55	.56	.55	.54	.55	.53
			E	.60	.59	.58	.59	.58	.57	.57	.56
			D	.64	.61	.60	.62	.60	.59	.60	.59
			C	.64	.63	.61	.63	.62	.60	.60	.60
			B	.65	.64	.63	.64	.63	.62	.62	.61
			A	.66	.65	.64	.64	.63	.62	.62	.62
 Direct: Wide Spread, Heavy-Duty Type	0 ↑ — ↓ 70	Spacing not to exceed 1.1 x MH MF G .80 M .72 P .65	J	.37	.34	.31	.36	.34	.31	.34	.31
			I	.45	.42	.41	.44	.41	.40	.41	.39
			H	.48	.46	.45	.49	.45	.44	.45	.44
			G	.52	.50	.48	.51	.49	.48	.49	.48
			F	.55	.52	.51	.54	.51	.50	.51	.50
			E	.57	.56	.54	.57	.55	.53	.55	.53
			D	.62	.59	.57	.60	.58	.57	.57	.56
			C	.63	.61	.58	.62	.59	.58	.59	.58
			B	.64	.62	.61	.63	.61	.60	.60	.59
			A	.66	.64	.62	.64	.62	.61	.62	.60
 Direct: R.L.M. Glassteel Diffuser	5 ↑ — ↓ 58	Spacing not to exceed 1 x MH MF G .70 M .60 P .45	J	.27	.23	.20	.26	.23	.20	.22	.20
			I	.34	.30	.28	.33	.29	.27	.29	.27
			H	.37	.34	.31	.36	.33	.31	.32	.30
			G	.40	.37	.34	.39	.36	.34	.35	.33
			F	.42	.39	.37	.40	.38	.36	.37	.36
			E	.46	.43	.41	.45	.42	.40	.41	.40
			D	.49	.47	.44	.48	.46	.44	.44	.43
			C	.51	.49	.46	.49	.47	.46	.46	.44
			B	.53	.51	.49	.51	.49	.48	.48	.47
			A	.54	.53	.51	.53	.51	.49	.49	.48
 Direct: R.L.M. Silvered Bowl Diffuser	0 ↑ — ↓ 67	Spacing not to exceed 0.8 x MH MF G .60 M .50 P .40	J	.38	.36	.35	.38	.36	.35	.38	.35
			I	.46	.45	.44	.45	.44	.43	.44	.42
			H	.49	.49	.48	.49	.48	.47	.48	.47
			G	.53	.52	.51	.52	.51	.50	.51	.49
			F	.55	.54	.53	.53	.53	.52	.53	.51
			E	.57	.57	.56	.57	.56	.55	.55	.54
			D	.61	.59	.58	.59	.58	.57	.57	.56
			C	.62	.61	.59	.60	.59	.58	.58	.57
			B	.63	.62	.61	.61	.60	.59	.59	.58
			A	.64	.63	.62	.62	.61	.60	.60	.59
 Direct: Wide Spread, Vapor Tight	0 ↑ — ↓ 65	Spacing not to exceed 1 x MH MF G .75 M .65 P .55	J	.31	.26	.23	.30	.26	.23	.26	.23
			I	.38	.34	.31	.37	.33	.31	.33	.31
			H	.41	.38	.34	.41	.38	.34	.37	.34
			G	.45	.41	.39	.44	.41	.39	.40	.39
			F	.47	.44	.41	.46	.43	.41	.43	.41
			E	.51	.48	.46	.50	.48	.46	.47	.46
			D	.55	.52	.50	.54	.52	.50	.51	.50
			C	.56	.54	.52	.55	.53	.52	.52	.51
			B	.59	.57	.55	.58	.56	.54	.55	.54
			A	.60	.58	.56	.59	.57	.56	.56	.55

Table 8-2. Continued

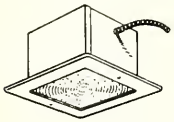
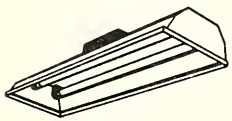
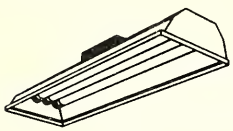
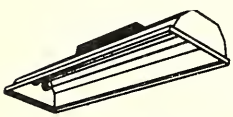
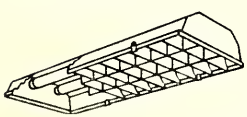
LUMINAIRE	DISTRIBUTION	SPACING and Maintenance Factor	Ceiling...	70%			50%			30%	
			Walls.....	50%	30%	10%	50%	30%	10%	30%	10%
			Room Index	COEFFICIENT OF UTILIZATION							
 Direct: Enclosed Lens-Plate Distributing Type	0 — 53	Spacing not to exceed 0.8 x MH MF G .70 M .60 P .50	J	.25	.22	.20	.24	.22	.20	.22	.20
			I	.31	.28	.26	.29	.28	.26	.28	.26
			H	.34	.31	.29	.32	.31	.29	.30	.28
			G	.36	.33	.32	.34	.33	.31	.32	.30
			F	.38	.35	.34	.36	.34	.33	.34	.32
			E	.40	.39	.38	.39	.37	.36	.37	.35
			D	.43	.41	.40	.42	.40	.39	.39	.38
			C	.45	.43	.42	.44	.41	.40	.40	.40
			B	.48	.45	.44	.47	.43	.42	.42	.41
			A	.50	.47	.46	.48	.46	.45	.45	.44
 Direct: Two 40-Watt Lamps	0 — 79	Spacing not to exceed 1 x MH MF G .65 M .55 P .45	J	.38	.32	.28	.37	.32	.28	.31	.28
			I	.47	.42	.39	.46	.41	.38	.40	.37
			H	.51	.47	.44	.50	.47	.43	.46	.43
			G	.55	.51	.48	.54	.51	.47	.50	.47
			F	.58	.54	.51	.57	.53	.51	.52	.50
			E	.63	.60	.57	.62	.59	.56	.58	.55
			D	.68	.64	.61	.66	.64	.61	.63	.60
			C	.70	.67	.63	.68	.65	.64	.64	.62
			B	.73	.70	.68	.71	.68	.67	.67	.66
			A	.74	.72	.70	.72	.70	.68	.69	.67
 Direct: Three 40-Watt Lamps	0 — 72	Spacing not to exceed 1 x MH MF G .65 M .55 P .45	J	.34	.29	.25	.33	.29	.25	.28	.25
			I	.42	.38	.35	.41	.37	.34	.37	.34
			H	.46	.42	.39	.44	.42	.39	.41	.39
			G	.50	.46	.43	.48	.45	.41	.44	.41
			F	.53	.49	.46	.51	.47	.44	.47	.44
			E	.57	.54	.51	.56	.52	.50	.52	.50
			D	.61	.58	.55	.59	.56	.54	.56	.54
			C	.63	.60	.57	.61	.58	.56	.58	.56
			B	.66	.64	.61	.64	.60	.59	.60	.59
			A	.67	.65	.62	.66	.62	.61	.62	.60
 Direct: Two 100-Watt Lamps	0 — 71	Spacing not to exceed 1 x MH MF G .60 M .50 P .45	J	.33	.28	.25	.33	.28	.25	.28	.25
			I	.41	.37	.34	.40	.36	.33	.36	.33
			H	.45	.41	.38	.44	.41	.38	.40	.38
			G	.48	.45	.42	.48	.45	.42	.43	.42
			F	.51	.48	.45	.50	.47	.45	.46	.45
			E	.55	.53	.50	.55	.52	.50	.51	.50
			D	.60	.57	.54	.58	.56	.54	.55	.54
			C	.61	.59	.56	.60	.57	.56	.57	.55
			B	.64	.62	.60	.62	.60	.59	.60	.58
			A	.65	.63	.61	.64	.62	.60	.61	.60
 Direct: With Louvers, two 40-Watt lamps	0 — 64	Spacing not to exceed 0.9 x MH MF G .65 M .55 P .45	J	.33	.28	.26	.32	.28	.26	.28	.26
			I	.39	.36	.34	.39	.35	.34	.35	.34
			H	.43	.40	.38	.42	.40	.38	.39	.38
			G	.46	.43	.41	.45	.43	.41	.42	.41
			F	.48	.46	.43	.47	.45	.43	.45	.43
			E	.52	.50	.47	.51	.49	.47	.48	.47
			D	.55	.53	.51	.54	.52	.51	.52	.51
			C	.57	.55	.52	.56	.53	.52	.53	.52
			B	.59	.57	.56	.57	.56	.55	.55	.54
			A	.60	.58	.56	.59	.57	.56	.56	.55

Table 8-2. Continued

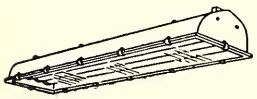
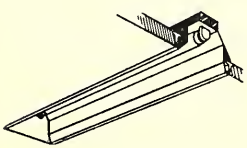
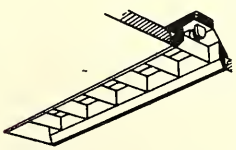
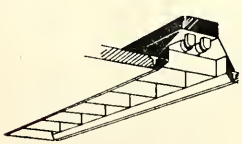
LUMINAIRE	DISTRIBUTION	SPACING and Maintenance Factor	Ceiling...	70%			50%			30%	
			Walls.....	50%	30%	10%	50%	30%	10%	30%	10%
			Room Index	COEFFICIENT OF UTILIZATION							
 Direct: Vapor and Dust Tight, two or three 40-watt Lamps	0 / 60	Spacing not to exceed 1 x MH MF G .70 M .65 P .55	J	.29	.26	.23	.28	.26	.23	.25	.23
			I	.35	.32	.31	.35	.32	.30	.32	.30
			H	.38	.36	.34	.38	.36	.34	.35	.34
			G	.41	.39	.37	.41	.39	.37	.38	.37
			F	.44	.41	.39	.42	.41	.39	.40	.39
			E	.46	.45	.42	.46	.44	.42	.44	.42
			D	.50	.48	.46	.49	.47	.46	.46	.46
			C	.51	.49	.47	.50	.48	.47	.48	.46
			B	.53	.51	.50	.52	.50	.49	.49	.49
			A	.54	.52	.50	.53	.51	.50	.50	.49
 Direct: Three Kw Reflector, one 3,000-Watt Mercury Lamp	0 / 80	Spacing not to exceed 1 x MH MF G .70 M .60 P .50	J	.38	.32	.28	.37	.32	.28	.31	.28
			I	.47	.42	.39	.46	.41	.38	.41	.38
			H	.51	.47	.43	.50	.47	.43	.46	.43
			G	.55	.51	.47	.54	.51	.47	.49	.47
			F	.58	.54	.51	.56	.53	.51	.52	.51
			E	.63	.59	.56	.62	.59	.56	.58	.56
			D	.67	.64	.61	.66	.63	.61	.63	.61
			C	.69	.67	.64	.67	.65	.63	.64	.63
			B	.72	.70	.67	.71	.68	.67	.67	.66
			A	.74	.71	.69	.72	.70	.68	.69	.67
 Direct: Troffer, Open Type	0 / 72	Spacing not to exceed 0.8 x MH MF G .70 M .60 P .55	J	.40	.37	.35	.39	.37	.35	.37	.35
			I	.48	.46	.45	.47	.45	.44	.44	.43
			H	.52	.50	.50	.51	.49	.49	.48	.48
			G	.55	.54	.53	.54	.53	.51	.51	.50
			F	.58	.56	.54	.55	.54	.53	.53	.52
			E	.60	.59	.57	.59	.58	.56	.57	.55
			D	.65	.62	.60	.62	.61	.59	.59	.58
			C	.66	.64	.61	.64	.62	.61	.61	.60
			B	.67	.65	.64	.65	.63	.62	.62	.61
			A	.68	.66	.65	.66	.65	.63	.64	.62
 Direct: Troffer with Louvers	0 / 65	Spacing not to exceed 0.8 x MH MF G .70 M .60 P .55	J	.32	.28	.25	.32	.28	.25	.28	.25
			I	.40	.36	.34	.39	.35	.33	.35	.33
			H	.43	.39	.37	.42	.39	.37	.39	.36
			G	.46	.43	.41	.45	.43	.41	.43	.40
			F	.48	.45	.43	.47	.45	.43	.45	.42
			E	.52	.50	.48	.51	.49	.47	.49	.46
			D	.56	.54	.52	.55	.53	.51	.53	.50
			C	.57	.55	.53	.56	.54	.52	.54	.51
			B	.60	.58	.56	.59	.57	.55	.56	.54
			A	.61	.59	.57	.60	.58	.57	.57	.56
 Direct: Troffer with Louvers	0 / 60	Spacing not to exceed 0.8 x MH MF G .70 M .60 P .55	J	.30	.26	.23	.29	.26	.23	.26	.23
			I	.37	.33	.31	.36	.32	.30	.32	.30
			H	.40	.36	.34	.39	.36	.34	.36	.33
			G	.42	.40	.38	.41	.40	.38	.40	.37
			F	.44	.41	.40	.43	.41	.40	.41	.39
			E	.48	.46	.44	.47	.45	.43	.45	.42
			D	.52	.50	.48	.51	.49	.47	.49	.46
			C	.53	.51	.49	.52	.50	.48	.50	.47
			B	.55	.53	.52	.54	.53	.51	.52	.50
			A	.56	.54	.53	.55	.54	.53	.53	.52

Table 8-2. Continued

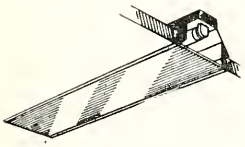
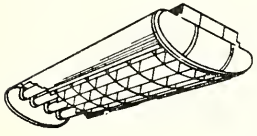
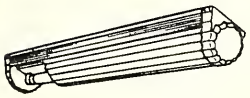
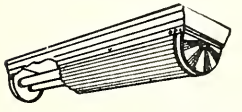
LUMINAIRE	DISTRIBUTION	SPACING and Maintenance Factors	Ceiling...	70%			50%			30%	
			Walls.....	50%	30%	10%	50%	30%	10%	30%	10%
			Room Index	COEFFICIENT OF UTILIZATION							
 0 55		Spacing not to exceed 1 x MH	J	.28	.24	.22	.27	.24	.22	.24	.22
			I	.34	.31	.29	.33	.30	.29	.30	.29
			H	.37	.34	.33	.36	.34	.32	.33	.32
			G	.39	.37	.36	.38	.37	.35	.38	.37
			F	.42	.39	.37	.40	.38	.37	.41	.40
			E	.44	.43	.40	.43	.42	.40	.42	.41
		MF	D	.47	.45	.43	.46	.45	.43	.44	.43
		G .70	C	.49	.47	.45	.47	.46	.45	.45	.44
		M .60	B	.50	.48	.47	.49	.47	.46	.46	.45
Direct: Troffer with Ribbed-Glass Cover		P .50	A	.51	.50	.48	.50	.48	.47	.47	.46
 0 60		Spacing not to exceed 1 x MH	J	.29	.26	.23	.28	.26	.23	.25	.23
			I	.35	.32	.31	.35	.32	.30	.32	.30
			H	.38	.36	.34	.38	.36	.34	.35	.34
			G	.41	.39	.37	.41	.39	.37	.38	.37
			F	.44	.41	.39	.42	.41	.39	.40	.39
			E	.46	.45	.42	.46	.44	.42	.44	.42
		MF	D	.50	.48	.46	.49	.47	.46	.46	.46
		G .70	C	.51	.49	.47	.50	.48	.47	.48	.46
		M .60	B	.53	.51	.50	.52	.50	.49	.49	.49
Direct: With Louvers four 40-Watt Lamps		P .55	A	.54	.52	.50	.53	.51	.50	.50	.49
 8 77		Spacing not to exceed 1 x MH	J	.32	.27	.23	.32	.26	.23	.25	.23
			I	.40	.35	.31	.39	.34	.30	.34	.30
			H	.44	.39	.36	.43	.39	.35	.36	.35
			G	.48	.43	.40	.46	.42	.39	.41	.39
			F	.52	.47	.43	.50	.46	.42	.45	.42
			E	.57	.52	.48	.55	.51	.47	.50	.46
		MF	D	.62	.56	.52	.59	.55	.51	.54	.51
		G .75	C	.65	.59	.54	.62	.57	.54	.56	.53
		M .65	B	.69	.63	.59	.65	.61	.58	.60	.58
Direct: Bare Lamp with White Reflecting Surface		P .55	A	.71	.66	.62	.67	.63	.60	.61	.60
 18 53		Spacing not to exceed 1 x MH	J	.23	.19	.17	.23	.18	.16	.17	.16
			I	.29	.25	.22	.28	.24	.21	.23	.21
			H	.32	.28	.25	.31	.28	.25	.26	.24
			G	.36	.32	.29	.34	.30	.27	.29	.26
			F	.40	.35	.31	.37	.33	.30	.31	.29
			E	.43	.39	.35	.41	.37	.34	.35	.32
		MF	D	.47	.42	.39	.44	.40	.37	.38	.36
		G .75	C	.49	.45	.41	.46	.42	.39	.40	.38
		M .65	B	.52	.48	.45	.49	.45	.43	.43	.41
Semidirect: Glass-Enclosed one 40-watt Lamp		P .55	A	.54	.51	.47	.51	.47	.45	.44	.43
 9 55		Spacing not to exceed 1 x MH	J	.24	.20	.19	.23	.20	.17	.19	.17
			I	.30	.26	.23	.29	.25	.23	.25	.23
			H	.33	.29	.27	.32	.29	.26	.28	.26
			G	.36	.32	.30	.34	.32	.29	.30	.29
			F	.39	.35	.32	.37	.34	.31	.33	.31
			E	.42	.39	.35	.41	.38	.35	.36	.34
		MF	D	.45	.42	.39	.44	.41	.38	.40	.38
		G .75	C	.47	.44	.41	.45	.42	.40	.41	.39
		M .65	B	.50	.47	.44	.48	.45	.43	.44	.42
Semidirect: Glass-Enclosed two 40-Watt Lamps		P .55	A	.52	.49	.46	.50	.47	.45	.45	.44

Table 8-2. Continued

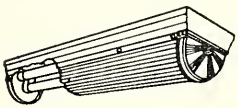
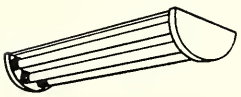
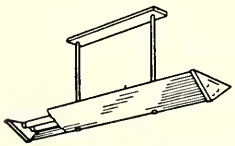
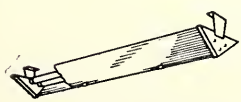
LUMINAIRE	DISTRIBUTION	SPACING and Maintenance Factor	Ceiling...	70%			50%			30%	
			Walls....	50%	30%	10%	50%	30%	10%	30%	10%
			Room Index	COEFFICIENT OF UTILIZATION							
 **Semidirect: Glass-Enclosed three 40-Watt Lamps**	8 / 50	Spacing not to exceed 1 x MH MF G .75 M .65 P .55	J	.21	.17	.14	.20	.16	.14	.16	.14
			I	.26	.22	.20	.25	.21	.19	.21	.19
			H	.29	.25	.23	.28	.25	.22	.24	.22
			G	.32	.28	.25	.30	.27	.25	.26	.24
			F	.34	.30	.27	.33	.30	.27	.29	.27
			E	.38	.34	.31	.36	.33	.31	.32	.30
			D	.41	.37	.34	.39	.36	.34	.35	.33
			C	.42	.39	.36	.41	.38	.36	.37	.35
			B	.45	.42	.39	.42	.40	.39	.39	.38
			A	.47	.44	.41	.45	.42	.40	.41	.39
 **Semidirect: Exposed Lamps**	25 / 60	Spacing not to exceed 1 x MH MF G .75 M .65 P .55	J	.27	.25	.19	.26	.22	.19	.20	.18
			I	.35	.29	.26	.33	.28	.25	.27	.24
			H	.38	.34	.30	.36	.32	.29	.30	.28
			G	.43	.38	.34	.40	.36	.32	.33	.31
			F	.46	.41	.37	.43	.39	.35	.37	.33
			E	.50	.46	.42	.47	.43	.40	.40	.38
			D	.55	.50	.46	.51	.47	.44	.44	.42
			C	.58	.53	.49	.53	.49	.46	.46	.44
			B	.62	.57	.53	.57	.53	.51	.50	.48
			A	.64	.60	.56	.59	.55	.52	.51	.49
 **General Diffuse: Totally Enclosed**	39 / 45	Spacing not to exceed 1.2 x MH MF G .75 M .70 P .65	J	.24	.19	.16	.22	.18	.15	.16	.14
			I	.29	.25	.22	.27	.23	.20	.21	.19
			H	.33	.28	.26	.30	.26	.24	.24	.21
			G	.37	.32	.29	.33	.29	.26	.26	.24
			F	.40	.36	.31	.36	.32	.29	.29	.26
			E	.45	.40	.36	.40	.36	.33	.32	.29
			D	.48	.43	.39	.43	.39	.36	.34	.33
			C	.51	.46	.42	.45	.41	.38	.37	.34
			B	.55	.50	.47	.49	.45	.42	.40	.38
			A	.57	.53	.49	.51	.47	.44	.41	.40
 Direct-Indirect: Suspension Type Two 40-Watt Lamps	47 / 36	Spacing not to exceed 1.2 x MH MF G .70 M .60 P .50	J	.26	.21	.18	.22	.19	.16	.16	.15
			I	.31	.26	.24	.27	.24	.22	.21	.19
			H	.34	.30	.28	.30	.27	.25	.24	.22
			G	.38	.34	.31	.34	.30	.28	.26	.25
			F	.41	.37	.33	.36	.33	.30	.28	.27
			E	.45	.41	.38	.40	.36	.34	.31	.30
			D	.49	.45	.42	.42	.41	.37	.34	.33
			C	.51	.48	.44	.44	.44	.39	.36	.34
			B	.55	.51	.49	.47	.45	.43	.38	.37
			A	.57	.53	.51	.49	.46	.44	.40	.38
 Semidirect: Ceiling Type Two 40-Watt Lamps	18 / 49	Spacing not to exceed 1.2 x MH MF G .70 M .60 P .50	J	.24	.20	.17	.23	.19	.16	.18	.16
			I	.30	.26	.23	.28	.24	.22	.24	.21
			H	.33	.29	.27	.31	.28	.26	.27	.25
			G	.36	.32	.29	.34	.31	.28	.29	.27
			F	.39	.35	.32	.36	.33	.31	.31	.30
			E	.42	.39	.36	.40	.37	.35	.35	.33
			D	.46	.43	.40	.43	.40	.38	.38	.37
			C	.48	.45	.42	.44	.42	.40	.40	.38
			B	.51	.48	.45	.47	.45	.43	.42	.41
			A	.52	.50	.47	.49	.46	.45	.43	.42

Table 8-2. Continued

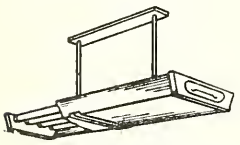
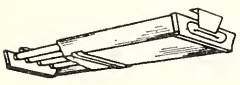
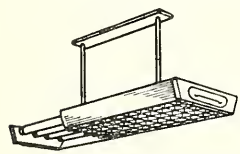
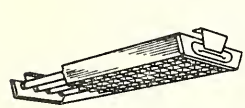
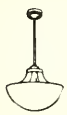
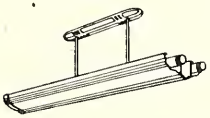
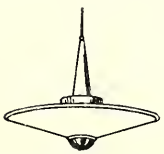
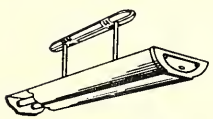
LUMINAIRE	DISTRIBUTION	SPACING and Maintenance Factor	Ceiling...	70%			50%			30%	
			Walls.....	50%	30%	10%	50%	30%	10%	30%	10%
			Room Index	COEFFICIENT OF UTILIZATION							
 Direct-Indirect: With Ribbed-Glass Bottom Four 40-Watt Lamps	46 / 33	Spacing not to exceed 1.2 x MH MF G .65 M .55 P .50	J	.27	.24	.22	.24	.22	.21	.21	.19
			I	.33	.30	.29	.29	.27	.26	.25	.23
			H	.36	.34	.32	.32	.30	.29	.28	.26
			G	.39	.37	.35	.36	.33	.32	.30	.28
			F	.43	.40	.37	.38	.35	.34	.31	.30
			E	.46	.43	.41	.41	.38	.37	.34	.32
			D	.50	.46	.44	.43	.41	.39	.36	.35
			C	.52	.49	.46	.45	.43	.41	.37	.36
			B	.55	.52	.50	.47	.45	.44	.38	.37
			A	.56	.54	.52	.49	.47	.45	.40	.38
 Semidirect: With Ribbed-Glass Bottom, Ceiling Type Four 40-Watt Lamps	14 / 45	Spacing not to exceed 0.9 x MH MF G .65 M .55 P .50	J	.25	.21	.19	.22	.20	.19	.18	.17
			I	.30	.28	.27	.27	.25	.24	.22	.21
			H	.33	.31	.30	.29	.27	.26	.25	.24
			G	.36	.34	.32	.31	.30	.28	.26	.26
			F	.38	.36	.34	.33	.31	.30	.28	.27
			E	.40	.39	.37	.35	.34	.32	.31	.29
			D	.43	.41	.39	.37	.36	.34	.32	.31
			C	.45	.43	.40	.39	.37	.36	.33	.32
			B	.47	.44	.43	.40	.38	.37	.34	.33
			A	.48	.46	.44	.41	.39	.38	.35	.34
 **Direct-Indirect with Louvers Suspension Type Four 40-Watt Lamps**	45 / 34	Spacing not to exceed 1.2 x MH MF G .70 M .65 P .60	J	.26	.23	.20	.23	.21	.19	.19	.17
			I	.31	.28	.27	.28	.26	.24	.23	.20
			H	.35	.32	.30	.31	.28	.27	.26	.24
			G	.38	.35	.33	.34	.31	.30	.28	.27
			F	.41	.38	.35	.36	.34	.32	.30	.28
			E	.44	.42	.39	.39	.37	.35	.32	.31
			D	.48	.45	.42	.42	.39	.38	.34	.33
			C	.50	.49	.44	.43	.41	.39	.35	.34
			B	.53	.50	.48	.46	.43	.42	.37	.36
			A	.54	.52	.50	.47	.45	.43	.39	.37
 Semidirect: With Louvers, Ceiling Type Four 40-Watt Lamps	15 / 45	Spacing not to exceed 0.9 x MH MF G .70 M .65 P .60	J	.24	.21	.19	.21	.19	.18	.19	.17
			I	.30	.27	.25	.26	.24	.23	.23	.21
			H	.32	.30	.28	.29	.27	.25	.25	.24
			G	.35	.33	.31	.31	.29	.28	.27	.26
			F	.38	.35	.32	.32	.31	.29	.29	.27
			E	.40	.38	.36	.35	.35	.32	.31	.29
			D	.43	.40	.39	.38	.36	.34	.32	.32
			C	.45	.42	.40	.39	.37	.35	.33	.32
			B	.47	.45	.43	.41	.39	.38	.34	.34
			A	.48	.46	.44	.42	.40	.38	.35	.34
 Semi-indirect: Totally Enclosed	66 / 20	Spacing not to exceed 1.2 x CH MF G .70 M .65 P .60	J	.20	.16	.13	.16	.13	.11	.10	.09
			I	.24	.20	.18	.20	.17	.15	.13	.12
			H	.28	.24	.21	.23	.19	.17	.15	.13
			G	.31	.27	.24	.26	.22	.20	.17	.15
			F	.34	.30	.27	.28	.24	.22	.19	.17
			E	.38	.34	.31	.31	.27	.25	.21	.19
			D	.42	.38	.35	.34	.30	.28	.23	.22
			C	.45	.41	.37	.36	.32	.30	.25	.23
			B	.49	.45	.42	.39	.36	.34	.27	.25
			A	.51	.47	.44	.41	.38	.36	.28	.27

Table 8-2. Continued

LUMINAIRE	DISTRIBUTION	SPACING and Maintenance Factor	Ceiling...	70%			50%			30%	
			Walls.....	50%	30%	10%	50%	30%	10%	30%	10%
			Room Index	COEFFICIENT OF UTILIZATION							
 Semi-indirect: Two 40-Watt Lamps	70 ↑ — ↓ 11	Spacing not to exceed 1.2 x CH MF G .60 M .50 P .40	J	.18	.14	.12	.14	.11	.09	.08	.07
			I	.22	.19	.17	.17	.15	.13	.10	.09
			H	.26	.22	.19	.20	.17	.15	.12	.10
			G	.29	.25	.22	.22	.19	.17	.14	.12
			F	.32	.28	.25	.24	.21	.19	.15	.14
			E	.35	.32	.29	.27	.24	.21	.17	.15
			D	.39	.35	.32	.29	.26	.24	.19	.18
			C	.42	.38	.35	.31	.28	.27	.20	.19
			B	.46	.42	.39	.34	.31	.29	.22	.21
			A	.48	.44	.42	.36	.33	.31	.23	.22
 Indirect: Glass	79 ↑ — ↓ 3	Spacing not to exceed 1.2 x CH MF G .65 M .60 P .50	J	.16	.13	.11	.12	.10	.08	.06	.05
			I	.20	.16	.15	.15	.13	.11	.08	.07
			H	.23	.20	.17	.17	.14	.13	.10	.08
			G	.26	.23	.20	.20	.17	.15	.11	.10
			F	.29	.26	.22	.22	.19	.17	.12	.11
			E	.32	.29	.26	.24	.21	.19	.13	.12
			D	.36	.32	.30	.26	.24	.22	.15	.14
			C	.38	.35	.32	.28	.25	.24	.16	.15
			B	.42	.39	.36	.30	.29	.27	.18	.17
			A	.44	.41	.39	.33	.30	.29	.19	.18
 Indirect: Silvered Bowl	85 ↑ — ↓ 0	Spacing not to exceed 1.2 x CH MF G .70 M .65 P .55	J	.17	.14	.12	.13	.11	.09	.07	.06
			I	.21	.17	.16	.16	.14	.12	.09	.08
			H	.24	.21	.18	.18	.15	.14	.11	.09
			G	.27	.24	.21	.21	.18	.16	.12	.11
			F	.30	.27	.23	.23	.20	.18	.13	.12
			E	.33	.30	.27	.25	.22	.20	.14	.13
			D	.37	.33	.31	.27	.25	.23	.16	.15
			C	.39	.36	.33	.29	.26	.25	.17	.16
			B	.43	.40	.37	.31	.30	.28	.19	.18
			A	.45	.42	.40	.34	.31	.30	.20	.19
 Indirect	80 ↑ — ↓ 0	Spacing not to exceed 1.2 x CH MF G .60 M .50 P .40	J	.15	.11	.10	.09	.08	.06	.04	.03
			I	.19	.15	.13	.12	.10	.09	.06	.04
			H	.22	.19	.16	.14	.12	.10	.07	.05
			G	.26	.22	.19	.17	.14	.13	.08	.07
			F	.28	.24	.21	.19	.16	.14	.09	.08
			E	.32	.28	.25	.21	.18	.17	.11	.10
			D	.35	.31	.29	.23	.21	.19	.12	.11
			C	.38	.34	.31	.25	.22	.21	.13	.12
			B	.42	.39	.36	.27	.25	.24	.15	.14
			A	.43	.41	.38	.29	.27	.25	.16	.15

Room index may be obtained from Table 8-3 or these equations:

indirect and semi-indirect luminaires;

$$\text{room index} = \frac{2 \times \text{room width} + \text{length (feet)}}{4 \times (\text{ceiling height (feet)} - 2.5)}$$

direct, semidirect, general diffuse, and direct-indirect luminaires;

$$\text{room index} = \frac{2 \times \text{room width} + \text{length (feet)}}{6 \times (\text{mounting height (feet)} - 2.5)}$$

It is current practice in tables (see 8-3) to use letter symbols.

Table 8-3. Room Indexes for a Wide Range of Room Sizes*

Index	0.6	0.8	1.0	1.25	1.5	2.0	2.5	3.0	4.0	5.0
Symbol	J	I	H	G	F	E	D	C	B	A

CEILING HEIGHT (FEET)

Semi-indirect and Indirect Luminaires	9 to 9½	10 to 11½	12 to 13½	14 to 16½	17 to 20	21 to 24	25 to 30	31 to 36	37 to 50		

MOUNTING HEIGHT ABOVE FLOOR (FEET)

Direct, Semidirect, General Diffuse, Direct-indirect Luminaires	7 to 7½	8 to 8½	9 to 9½	10 to 11½	12 to 13½	14 to 16½	17 to 20	21 to 24	25 to 30	31 to 36	37 to 50

ROOM WIDTH* (Feet)	ROOM LENGTH* (Feet)	ROOM INDEX										
9 (8½–9)	8–10	H	I	J	J							
	10–14	H	I	I	J							
	14–20	G	H	I	J	J						
	20–30	G	G	H	I	J	J					
	30–42	F	G	H	I	J	J	J				
	42–up	E	F	G	H	I	J	J				
10 (9½–10½)	10–14	G	H	I	J	J						
	14–20	G	H	I	J	J	J					
	20–30	F	G	H	I	J	J					
	30–42	F	G	G	H	I	J	J				
	42–60	E	F	G	H	I	J	J				
	60–up	E	F	F	H	H	I	J				
12 (11–12½)	11–14	G	H	I	I	J	J					
	14–20	F	G	H	I	J	J					
	20–30	F	G	G	H	I	J	J				
	30–42	E	F	G	H	I	J	J				
	42–60	E	F	F	G	H	I	J				
	60–up	E	E	F	G	H	I	J				
14 (13–15½)	13–20	F	G	H	H	I	J	J				
	20–30	E	F	G	H	I	J	J				
	30–42	E	F	F	G	H	I	J	J			
	42–60	E	E	F	F	H	I	J	J	J		
	60–90	D	E	E	F	G	H	J	J	J		
	90–up	D	E	E	F	F	G	I	J	J		
17 (16–18½)	16–20	E	F	G	H	I	J	J				
	20–30	E	F	F	G	H	I	J				
	30–42	D	E	F	G	H	H	J	J	J		
	42–60	D	E	E	F	G	G	I	J	J	J	
	60–110	D	E	E	F	G	G	I	J	J	J	
	110–up	C	D	E	E	F	G	H	I	J	J	
20 (19–21½)	20–30	D	E	F	G	H	I	J	J			
	30–42	D	E	E	F	G	H	I	J	J		
	42–60	D	D	E	E	F	G	I	J	J	J	
	60–90	C	D	E	E	F	G	H	J	J	J	
	90–140	C	D	D	E	F	F	H	I	I	J	J
	140–up	C	D	D	E	F	F	H	H	I	J	J

* For areas with dimensions greater than those shown in the table, use the following procedure to determine the room index:

1. Divide length and width by some common number which reduces dimensions to values within limits of table.
2. Subtract 2½ ft from the mounting height (or ceiling height) and divide this dimension by same divisor used in step 1.
3. Add 2½ ft to reduced height dimension and select the room index from the above table according to these new dimensions.

Table 8-3. Continued

	CEILING HEIGHT (FEET)											
Semi-indirect and Indirect Luminaires	9 to 9½	10 to 11½	12 to 13½	14 to 16½	17 to 20	21 to 24	25 to 30	31 to 36	37 to 50			
	MOUNTING HEIGHT ABOVE FLOOR (FEET)											
Direct, Semidirect, General Diffuse, Direct-indirect Luminaires	7 to 7½	8 to 8½	9 to 9½	10 to 11½	12 to 13½	14 to 16½	17 to 20	21 to 24	25 to 30	31 to 36	37 to 50	
ROOM WIDTH* (Feet)	ROOM LENGTH* (Feet)	ROOM INDEX										
24 (22–26)	22–30	D	E	E	F	G	H	I	J	J		
	30–42	C	D	E	F	G	G	I	J	J		
	42–60	C	D	D	E	F	G	H	I	J	J	
	60–90	C	D	D	E	F	F	H	I	J	J	J
	90–140	C	C	D	E	E	F	G	H	I	J	J
	140–up	C	C	D	E	E	F	G	H	I	I	J
30 (27–33)	27–42	C	D	D	E	F	G	H	I	J	J	
	42–60	C	C	D	D	F	F	H	H	I	J	
	60–90	B	C	C	D	E	F	G	H	I	J	
	90–140	B	C	C	D	E	E	F	G	H	I	J
	140–180	B	C	C	D	E	E	F	G	H	I	J
	180–up	B	C	C	D	E	E	F	G	H	I	J
36 (34–39)	34–42	B	C	D	E	F	F	H	I	I	J	
	42–60	B	C	C	D	E	F	G	H	I	J	J
	60–90	A	C	C	C	E	E	F	H	H	J	J
	90–140	A	B	C	C	D	E	F	G	H	I	J
	140–200	A	B	C	C	D	E	F	F	G	H	I
	200–up	A	B	C	C	D	E	F	F	G	H	I
42 (40–45)	40–60	A	B	C	C	E	F	G	H	I	I	J
	60–90	A	B	B	C	D	E	F	G	H	I	J
	90–140	A	B	B	C	D	E	E	F	G	H	J
	140–200	A	A	B	C	D	D	E	F	G	H	I
	200–up	A	A	B	C	D	D	E	F	F	G	I
50 (46–55)	46–60	A	A	B	C	D	E	F	G	H	I	J
	60–90	A	A	B	C	C	D	F	F	G	H	J
	90–140	A	A	A	C	C	D	E	F	F	G	I
	140–200	A	A	A	C	C	D	E	E	F	G	I
	200–up	A	A	A	C	C	D	E	E	F	G	H
60 (56–67)	56–90	A	A	A	B	C	D	E	F	G	H	I
	90–140	A	A	A	B	C	C	D	E	F	G	H
	140–200	A	A	A	B	C	C	D	E	E	F	H
	200–up	A	A	A	B	C	C	D	E	E	F	H
75 (68–90)	68–90	A	A	A	A	B	C	D	E	F	G	I
	90–140	A	A	A	A	B	C	D	E	F	F	H
	140–200	A	A	A	A	B	B	C	D	E	F	G
	200–up	A	A	A	A	B	B	C	D	E	F	G
90 or more	90–140	A	A	A	A	A	B	C	D	E	F	G
	140–200	A	A	A	A	A	B	C	D	E	F	G
	200–up	A	A	A	A	A	B	C	C	D	E	F

The *coefficient of utilization* may be obtained from Table 8-2 or by computation. In either case it is necessary to know, measure, or estimate the following: length, width, and ceiling height of the room; average luminous reflectance of walls and ceiling;* the candlepower distribution curve; and mounting height (above the floor) of the luminaire.

The coefficient of utilization equals the total lumens utilized divided by the rated lamp lumens:

$$k_u = \frac{F_u}{F_l}$$

The total lumens emitted in each zone may be determined using the nomogram Appendix Fig. A-3 or the zonal constants in Appendix Table A-30 and the distribution curve. The procedure for the zonal constants (symmetric distribution) is as follows:

1. Determine the lumens in each zone between 0 degree and 180 degrees beginning at the intersection of the vertical axis and the bottom of the luminaire, by multiplying the average candlepower in each zone by the zonal constant. Tabulate these values, the rated lamp lumens, and H, the candlepower at 90 degrees, on a form such as Table 8-4.
2. Obtain the following sums:
 Lumens in 0-degree to 40-degree zone (C)
 Lumens in 0-degree to 90-degree zone (D)
 Lumens in 90-degree to 180-degree zone (I)
3. Determine per cent of flux in 0 degree to 40 degree zone:

$$F_{0-40} = \frac{C - 0.65H}{D - 5.0H}$$

Determine from Table 8-5 the classification of the direct component and enter in Table 8-4. Select from Table 8-5 the direct component multiplying factor corresponding to the recorded ceiling and wall reflectances, room index, and component classification; enter in Table 8-4.

4. Compute the directional components:
 Direct = $(D) - 5\,(H)$
 Horizontal = $10\,(H)$
 Indirect = $(I) - 5\,(H)$

and enter the utilized lumens component, (F_u) = (directional component $\times$ multiplying factor), in Table 8–4.

5. To obtain the coefficient of utilization for each room index, wall reflectance, and ceiling reflectance combination, add the three utilized lumen components and divide by the rated lamp lumens; enter in Table 8-4.

* The average reflectance of a given wall area is determined by multiplying the area of each window, door, drapery, woodwork section, mirror, picture, tapestry, and so forth, by its reflectance and dividing the sum of the results by the total area. Since clear glass has a reflectance of only about 8 per cent, a full shade or Venetian blind with a reflectance of 50 to 80 per cent, when it is drawn to cover a window, will increase the average reflectance and, therefore, the utilization coefficient of a room.

Table 8-4. Coefficient of Utilization Computation Sheet

Room Index:
Ceiling Reflectance (r_c):%
Candlepower at 90° (H):

Rated Lamp Lumens:(Fl)
Wall Reflectance (r_w):%

ZONE	LUMENS	ZONE	LUMENS
0°–10°		90–100	
10 –20		100–110	
20 –30		110–120	
30 –40		120–130	
	lumens 0°–40° (C)		
40 –50		130–140	
50 –60		140–150	
60 –70		150–160	
70 –80		160–170	
80 –90		170–180	
	lumens 0°–90° (D)		lumens 90°–180° (I)

Classification of direct component:
Horizontal component = 10 (H) = ...
Indirect component = (I) − 5 (H) = ...
Direct component = (D) − 5 (H) = ...

r_c ..:		70%			50%			30%	
r_w		50%	30%	10%	50%	30%	10%	30%	10%
Room Index	Component	Mult. Factor \| *F_u	Mult. Factor \| F_u	Mult. Factor \| F_u	Mult. Factor \| F_u	Mult. Factor \| F_u	Mult. Factor \| F_u	Mult. Factor \| F_u	Mult. Factor \| F_u
	Ind	.19	.15	.13	.13	.11	.09	.06	.05
	Hor	.21	.15	.11	.19	.13	.10	.11	.09
J	Dir								
0.6	K_u	$=\Sigma\frac{F_u}{Fl}$							
	Ind	.23	.19	.17	.17	.14	.12	.08	.07
	Hor	.27	.20	.16	.24	.18	.14	.16	.13
I	Dir								
0.8	K_u								
	Ind	.27	.23	.20	.19	.16	.14	.10	.08
	Hor	.31	.24	.20	.28	.22	.18	.19	.15
H	Dir								
1.0	K_u								
	Ind	.31	.27	.23	.23	.19	.17	.11	.10
	Hor	.36	.29	.24	.31	.25	.21	.22	.18
G	Dir								
1.25	K_u								
	Ind	.34	.30	.26	.25	.21	.19	.12	.11
	Hor	.40	.33	.27	.35	.29	.24	.25	.21
F	Dir								
1.5	K_u								
	Ind	.38	.34	.31	.28	.24	.22	.14	.13
	Hor	.46	.39	.35	.40	.34	.29	.29	.25
E	Dir								
2.0	K_u								
	Ind	.42	.38	.35	.30	.27	.25	.16	.15
	Hor	.50	.43	.37	.44	.38	.33	.33	.29
D	Dir								
2.5	K_u								
	Ind	.45	.41	.38	.32	.29	.27	.17	.16
	Hor	.54	.47	.41	.47	.41	.36	.36	.32
C	Dir								
3.0	K_u								
	Ind	.50	.46	.43	.35	.33	.31	.19	.18
	Hor	.60	.53	.47	.52	.46	.42	.40	.37
B	Dir								
4.0	K_u								
	Ind	.52	.48	.46	.38	.35	.33	.21	.19
	Hor	.63	.57	.51	.55	.49	.45	.42	.40
A	Dir								
5.0	K_u								

* F_u = directional component × multiplying factor.

Table 8-5. Universal Multiplying Factors for Direct Components of Utilization Coefficients

DIRECT COMPONENT CLASSIFICATION

Flux in 0° to 40° zone (Per cent)	CLASSIFICATION	
35–40	B	Broad
40–45	M	Medium
45–50	N	Narrow
50–55	VN	Very narrow
55–60	C	Concentrating
More than 60	F	Focusing

Ceiling Reflectance	0.75																		0.5					
Direct Component Classification	B			M			N			VN			C			F			B			M		
Wall Reflectance	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1
Room Index	MULTIPLYING FACTORS																							
J-0.6	.44	.36	.30	.47	.40	.35	.50	.44	.40	.53	.48	.45	.55	.51	.45	.57	.54	.52	.43	.36	.30	.46	.40	.35
I-0.8	.55	.48	.43	.58	.52	.48	.48	.61	.56	.64	.60	.59	.66	.63	.62	.68	.66	.65	.54	.47	.42	.57	.51	.47
H-1.0	.60	.54	.49	.63	.58	.54	.66	.62	.59	.69	.66	.64	.71	.69	.68	.73	.72	.71	.59	.54	.49	.62	.58	.54
G-1.25	.65	.59	.54	.68	.63	.59	.71	.67	.64	.74	.71	.69	.76	.74	.73	.78	.77	.76	.64	.59	.54	.67	.63	.59
F-1.5	.69	.63	.58	.72	.67	.63	.75	.71	.67	.78	.75	.71	.80	.78	.75	.82	.80	.78	.67	.62	.58	.70	.66	.63
E-2.0	.75	.70	.65	.78	.74	.70	.80	.77	.73	.82	.80	.77	.84	.83	.80	.85	.84	.83	.74	.69	.65	.77	.73	.70
D-2.5	.81	.77	.72	.84	.80	.76	.86	.82	.79	.88	.84	.82	.90	.86	.84	.91	.87	.86	.79	.76	.72	.82	.79	.76
C-3.0	.84	.80	.76	.86	.83	.79	.88	.85	.81	.90	.87	.83	.91	.89	.85	.92	.90	.87	.82	.78	.76	.84	.81	.79
B-4.0	.88	.85	.82	.90	.87	.84	.91	.88	.86	.92	.89	.88	.93	.90	.89	.93	.91	.90	.86	.83	.81	.88	.85	.83
A-5.0	.91	.87	.84	.92	.89	.86	.93	.90	.87	.94	.91	.89	.94	.92	.90	.94	.93	.91	.89	.85	.83	.90	.87	.85

Ceiling Reflectance	0.5												0.3											
Direct Component Classification	N			VN			C			F			B		M		N		VN		C		F	
Wall Reflectance	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.3	0.1	0.3	0.1	0.3	0.1	0.3	0.1	0.3	0.1	0.3	0.1
Room Index	MULTIPLYING FACTORS																							
J-0.6	.49	.44	.40	.52	.48	.45	.54	.51	.49	.56	.54	.52	.35	.30	.39	.35	.43	.40	.48	.44	.52	.48	.56	.51
I-0.8	.60	.55	.52	.63	.59	.57	.65	.62	.61	.67	.65	.64	.47	.42	.51	.47	.55	.52	.59	.56	.62	.59	.65	.62
H-1.0	.65	.62	.59	.68	.65	.63	.70	.68	.67	.72	.71	.70	.53	.49	.57	.54	.61	.59	.65	.63	.68	.66	.71	.69
G-1.25	.70	.67	.64	.73	.70	.68	.75	.73	.71	.77	.75	.74	.57	.54	.61	.59	.65	.64	.69	.68	.72	.71	.75	.73
F-1 5	.73	.70	.67	.75	.73	.71	.77	.76	.74	.79	.78	.77	.61	.58	.65	.63	.69	.67	.73	.71	.76	.74	.78	.76
E-2.0	.79	.76	.73	.81	.79	.76	.83	.81	.79	.84	.83	.81	.68	.65	.72	.70	.75	.73	.78	.76	.80	.78	.82	.80
D-2.5	.84	.81	.79	.86	.83	.81	.87	.85	.83	.88	.86	.85	.75	.72	.78	.76	.80	.79	.82	.81	.84	.83	.85	.84
C-3.0	.86	.83	.81	.88	.85	.83	.89	.87	.85	.90	.88	.86	.77	.75	.80	.78	.82	.80	.84	.82	.85	.84	.86	.85
B-4.0	.89	.86	.85	.90	.87	.86	.91	.88	.87	.91	.89	.88	.82	.80	.84	.82	.85	.84	.86	.85	.87	.86	.88	.87
A-5.0	.91	.88	.86	.92	.89	.87	.92	.90	.88	.92	.90	.89	.84	.82	.86	.84	.87	.85	.88	.86	.89	.87	.89	.88

AVERAGE BRIGHTNESS

It has long been realized that brightness as well as illumination must be considered in lighting design. Recently a committee of the Illuminating Engineering Society developed a simple method of predicting average brightness values in interiors.[6] The procedure, based on the original work of Buckley,[7] Hisano,[8] Yamauti,[9] Moon,[10] and Spencer,[10] is as follows:

1. Obtain the average maintained illumination level (E_{av}), using Table 8-1 or the lumen method and record on a form such as Table 8-6 with the data indicated.

2. Compute and enter in Table 8-6 the room coefficient k_r (similar in concept to the room index) using the following equation:

$$k_r = \frac{h(l + w)}{2\ lw}$$

where h = ceiling height l = length of room w = width of room

3. The average maintained brightnesses (in footlamberts) of various areas may now be determined using the equations of Table 8-6.

The best conditions for critical seeing are those for which the ratio of any of the brightness values just given to the brightness of the task falls within the range $\frac{1}{3}$–3.[6]

Table 8-6. Average Brightness Calculation Sheet[6]

Average maintained illumination E_{av} = ... footcandles
Type of lighting: Direct □; General Diffuse □; Indirect □.
Average reflectance:
task (r_t) floor (r_f)
working plane (r_p) wall (r_w)(see note.)
ceiling (r_c)
Room dimensions: ceiling height (h) ft; length (l) ft; width (w) ft
Room coefficient: $k_r = \frac{h\ (l + w)}{2\ lw}$ =

Brightnesses

Task: $B_t = E_{av} \times r_t$ = ... footlamberts
Working plane: $B_p = E_{av} \times r_p$ = ... footlamberts
Floor: $B_f = E_{av} \times \frac{B_f}{E_{av}}$* = ... footlamberts
Walls midway to ceiling: $B_{mw} = E_{av} \times \frac{B_{mw}}{E_{av}}$† = ... footlamberts
Walls near ceiling: $B_{tw} = E_{av} \times \frac{B_{tw}}{E_{av}}$‡ = ... footlamberts
Ceiling: $B_c = E_{av} \times \frac{B_c}{E_{av}}$§ = ... footlamberts

* From Table 8-7A. ‡ From Table 8-7C.
† From Table 8-7B. § From Table 8-7D.

Note: The average reflectance of a given wall area is determined by multiplying the area of each window, door, drapery, woodwork section, mirror, picture, tapestry, and so forth, by its reflectance and dividing the sum of the results by the total area. Since clear glass has a reflectance of only about 8 per cent, a full shade or Venetian blind with reflectance of 50 to 80 per cent, when it is drawn to cover a window, will increase the average reflectance and, therefore, the utilization coefficient of a room.

Table 8-7. Brightness Ratios For Direct, Indirect, and General Diffuse Lighting Installations in a Variety of Rooms[6]

A. AVERAGE FLOOR BRIGHTNESS (B_f)/AVERAGE ILLUMINATION LEVEL (E_{av})

Ceiling reflectance r_c	0.8			0.7			0.5		
Wall reflectance r_w	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1
Room coefficient K_r									
Direct and Indirect Lighting	floor reflectance r_f = 0.3								
0.1	0.290	0.288	0.286	0.290	0.288	0.286	0.290	0.288	0.286
0.2	.280	.277	.273	.280	.277	.273	.280	.277	.273
0.3	.271	.266	.261	.271	.266	.261	.271	.266	.261
0.4	.262	.255	.249	.262	.255	.249	.262	.255	.249
0.5	.253	.245	.237	.253	.245	.237	.253	.245	.237
0.7	.236	.226	.216	.236	.226	.216	.236	.226	.215
1.0	.213	.200	.188	.213	.200	.188	.213	.200	.186
Direct and Indirect Lighting	floor reflectance r_f = 0.1								
0.1	0.096	0.096	0.095	0.096	0.096	0.095	0.096	0.096	0.095
0.2	.093	.092	.091	.093	.092	.091	.093	.092	.091
0.3	.090	.088	.087	.090	.088	.087	.090	.088	.087
0.4	.087	.085	.083	.087	.085	.083	.087	.085	.083
0.5	.083	.081	.079	.083	.081	.079	.083	.081	.079
0.7	.078	.075	.072	.078	.075	.072	.078	.075	.072
1.0	.070	.066	.062	.070	.066	.062	.070	.066	.062
General Diffuse Lighting	floor reflectance r_f = 0.3								
0.1	0.298	0.295	0.293	0.298	0.296	0.294	0.300	0.297	0.295
0.2	.295	.291	.287	.296	.292	.288	.299	.293	.291
0.3	.292	.287	.282	.293	.289	.284	.298	.289	.287
0.4	.289	.283	.277	.291	.285	.280	.296	.285	.284
0.5	.286	.280	.274	.288	.282	.276	.295	.281	.281
0.7	.281	.275	.268	.284	.278	.271	.295	.274	.277
1.0	.275	.270	.263	.279	.274	.266	.288	.265	.274
General Diffuse Lighting	floor reflectance r_f = 0.1								
0.1	0.099	0.099	0.098	0.100	0.099	0.098	0.010	0.099	0.099
0.2	.098	.097	.092	.099	.098	.096	.100	.099	.097
0.3	.097	.096	.091	.098	.096	.095	.099	.098	.096
0.4	.096	.095	.091	.097	.095	.093	.099	.097	.095
0.5	.095	.093	.090	.096	.094	.092	.098	.096	.094
0.7	.093	.091	.088	.094	.092	.090	.097	.095	.093
1.0	.091	.089	.087	.092	.091	.089	.095	.093	.091

Table 8-7. Continued

B. AVERAGE WALL BRIGHTNESS HALFWAY BETWEEN FLOOR AND CEILING (B_{wm})/AVERAGE ILLUMINATION LEVEL (E_{av})

Ceiling reflectance r_c	0.8			0.7			0.5		
Wall reflectance r_w	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1
Room coefficient Kr									
Direct and Indirect Lighting	floor reflectance r_f = 0.3								
0.1	0.332	0.198	0.657	0.332	0.198	0.657	0.332	0.198	0.656
0.2	.340	.202	.667	.340	.202	.667	.340	.202	.667
0.3	.348	.206	.680	.348	.206	.680	.348	.206	.680
0.4	.357	.212	.697	.357	.212	.697	.357	.212	.696
0.5	.367	.218	.717	.367	.218	.717	.367	.218	.716
0.7	.389	.231	.765	.388	.231	.765	.388	.231	.762
1.0	.426	.256	.856	.426	.256	.856	.426	.256	.851
Direct and Indirect Lighting	floor reflectance r_f = 0.1								
0.1	0.288	0.172	0.057	0.288	0.172	0.057	0.288	0.172	0.057
0.2	.300	.179	.059	.300	.179	.059	.300	.179	.059
0.3	.313	.186	.062	.313	.186	.062	.313	.186	.062
0.4	.327	.194	.064	.327	.194	.064	.327	.194	.064
0.5	.340	.202	.067	.340	.202	.067	.340	.202	.067
0.7	.368	.220	.073	.368	.220	.073	.368	.220	.073
1.0	.413	.249	.083	.413	.249	.083	.413	.249	.083
General Diffuse Lighting	floor reflectance r_f = 0.3								
0.1	0.442	0.268	0.090	0.453	0.274	0.092	0.478	0.289	0.098
0.2	.455	.278	.095	.464	.284	.097	.490	.298	.010
0.3	.466	.287	.099	.476	.294	.010	.500	.306	.011
0.4	.478	.297	.010	.488	.304	.105	.512	.313	.111
0.5	.490	.307	.107	.450	.314	.110	.523	.320	.115
0.7	.514	.328	.117	.523	.334	.119	.545	.334	.125
1.0	.551	.359	.131	.559	.364	.133	.576	.354	.138
General Diffuse Lighting	floor reflectance r_f = 0.1								
0.1	0.415	0.252	0.085	0.424	0.257	0.087	0.447	0.271	0.091
0.2	.427	.262	.085	.437	.268	.091	.460	.382	.096
0.3	.441	.272	.091	.450	.278	.096	.473	.293	.010
0.4	.454	.283	.096	.464	.289	.010	.487	.304	.106
0.5	.468	.294	.010	.477	.300	.105	.500	.315	.110
0.7	.496	.316	.112	.505	.322	.115	.525	.336	.120
1.0	.538	.350	.127	.545	.356	.130	.562	.368	.135

Table 8-7. Continued

C. AVERAGE WALL BRIGHTNESS NEAR CEILING (B_{wt})/AVERAGE ILLUMINATION LEVEL (E_{av})

Ceiling reflectance r_c	0.8			0.7			0.5		
Wall reflectance r_w	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1
Room coefficient Kr									
Direct and Indirect Lighting	floor reflectance r_f = 0.3								
0.1	0.351	0.210	0.070	0.351	0.210	0.070	0.351	0.210	0.070
0.2	.382	.229	.077	.382	.229	.077	.382	.229	.077
0.3	.418	.253	.085	.418	.253	.085	.418	.253	.085
0.4	.459	.281	.096	.459	.281	.096	.459	.281	.096
0.5	.506	.314	.011	.506	.314	.011	.506	.314	.011
0.7	.618	.397	.141	.618	.397	.141	.618	.397	.141
1.0	.084	.057	.214	.084	.057	.214	.084	.057	.212
Direct and Indirect Lighting	floor reflectance r_f = 0.1								
0.1	0.311	0.187	0.062	0.311	0.186	0.062	0.311	0.186	0.062
0.2	.351	.211	.070	.351	.211	.070	.351	.211	.070
0.3	.394	.239	.080	.394	.239	.080	.394	.239	.080
0.4	.441	.270	.092	.441	.270	.092	.441	.270	.092
0.5	.493	.306	.011	.493	.306	.011	.493	.306	.011
0.7	.614	.393	.140	.614	.393	.140	.614	.393	.140
1.0	.085	.057	.213	.085	.057	.213	.085	.057	.213
General Diffuse Lighting	floor reflectance r_f = 0.3								
0.1	0.450	0.273	0.092	0.459	0.279	0 094	0.482	0.292	0.099
0.2	.472	.289	.099	.479	.294	.100	.498	.304	.010
0.3	.492	.306	.011	.499	.310	.107	.514	.316	.111
0.4	.516	.324	.113	.520	.327	.115	.532	.329	.117
0.5	.540	.344	.122	.543	.345	.123	.549	.342	.125
0.7	.591	.386	.140	.589	.385	.140	.584	.368	.140
1.0	.671	.455	.172	.661	.449	.170	.636	.409	.166
General Diffuse Lighting	floor reflectance r_f = 0.1								
0.1	0.425	0.258	0.087	0.434	0.263	0.089	0.454	0.275	0.093
0.2	.449	.276	.090	.457	.280	.096	.474	.291	.099
0.3	.474	.295	.099	.480	.299	.010	.495	.308	.011
0.4	.501	.315	.011	.505	.318	.111	.516	.325	.114
0.5	.528	.336	.117	.530	.338	.120	.537	.342	.122
0.7	.584	.381	.137	.582	.380	.138	.577	.378	.138
1.0	.671	.453	.170	.660	.447	.169	.636	.433	.165

Table 8-7. Continued

D. AVERAGE CEILING BRIGHTNESS (B_c)/AVERAGE ILLUMINATION LEVEL (E_{av})

Ceiling reflectance r_c	0.8			0.7			0.5		
Wall reflectance r_w	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1
Room coefficient Kr									
Direct Lighting	floor reflectance $r_f = 0.3$								
0.1	0.261	0.238	0.216	0.223	0.204	0.185	0.149	0.136	0.123
0.2	.266	.221	.180	.226	.190	.154	.151	.127	.010
0.3	.271	.212	.153	.232	.181	.131	.154	.121	.087
0.4	.283	.208	.134	.243	.178	.115	.162	.118	.076
0.5	.299	.210	.120	.257	.180	.010	.171	.120	.069
0.7	.345	.229	.108	.296	.196	.092	.197	.131	.062
1.0	.045	.204	.118	.038	.252	.010	.257	.168	.068
Direct Lighting	floor reflectance $r_f = 0.1$								
0.1	0.115	0.096	0.077	0.098	0.082	0.066	0.066	0.055	0.044
0.2	.142	.011	.071	.012	.091	.061	.081	.061	.040
0.3	.171	.119	.067	.046	.010	.057	.097	.068	.038
0.4	.200	.133	.066	.071	.114	.056	.011	.076	.037
0.5	.231	.149	.067	.098	.128	.057	.132	.085	.038
0.7	.299	.190	.074	.256	.162	.064	.171	.011	.043
1.0	.425	.274	.102	.365	.235	.087	.243	.157	.058
Indirect Lighting	floor reflectance $r_f = 0.3$								
0.1	1.108	1.129	1.151	1.108	1.129	1.151	1.108	1.129	1.151
0.2	1.228	1.277	1.326	1.228	1.277	1.326	1.228	1.277	1.326
0.3	1.363	1.446	1.528	1.363	1.448	1.528	1.363	1.448	1.529
0.4	1.514	1.638	1.761	1.514	1.638	1.761	1.514	1.638	1.759
0.5	1.682	1.856	2.030	1.682	1.856	2.030	1.682	1.856	2.027
0.7	2.078	2.386	2.699	2.078	2.386	2.699	2.078	2.386	2.691
1.0	2.861	3.481	4.138	2.861	3.481	4.318	2.861	3.481	4.112
	floor reflectance $r_f = 0.1$								
0.1	1.114	1.134	1.153	1.114	1.134	1.152	1.114	1.134	1.152
0.2	1.241	1.285	1.328	1.241	1.285	1.328	1.241	1.285	1.328
0.3	1.381	1.457	1.531	1.381	1.457	1.531	1.381	1.457	1.531
0.4	1.537	1.651	1.765	1.537	1.651	1.765	1.537	1.651	1.765
0.5	1.710	1.872	2.035	1.710	1.872	2.035	1.710	1.872	2.035
0.7	2.113	2.406	2.705	2.113	2.406	2.705	2.113	2.406	2.705
1.0	2.906	3.506	4.146	2.906	3.506	4.146	2.905	3.506	4.146

Table 8-7. D Continued

Ceiling reflectance r_c	0.8			0.7			0.5		
Wall reflectance r_w	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1
Room coefficient Kr									
General Diffuse Lighting	floor reflectance $r_f = 0.3$								
0.1	0.634	0.633	0.631	0.589	0.587	0.586	0.479	0.477	0.476
0.2	.694	.693	.650	.642	.643	.645	.522	.520	.524
0.3	.748	.758	.767	.694	.702	.762	.561	.563	.577
0.4	.805	.826	.848	.745	.764	.849	.602	.606	.635
0.5	.864	.898	.936	.797	.830	.942	.640	.650	.697
0.7	.982	1.054	1.135	.902	.969	1.144	.715	.740	.833
1.0	1.167	1.310	1.483	1.062	1.195	1.485	.825	.878	1.061
General Diffuse Lighting	floor reflectance $r_f = 0.1$								
0.1	0.564	0.563	0.561	0.523	0.522	0.521	0.425	0.424	0.423
0.2	.634	.637	.612	.589	.591	.593	.478	.480	.481
0.3	.703	.712	.699	.651	.660	.669	.527	.535	.543
0.4	.769	.789	.792	.711	.731	.751	.574	.590	.607
0.5	.835	.869	.891	.771	.803	.838	.619	.645	.675
0.7	.967	1.036	1.104	.888	.953	1.026	.704	.757	.819
1.0	1.166	1.305	1.465	1.061	1.190	1.345	.824	.929	1.055

Luminaire Spacing

In planning general-lighting systems the aim is to provide a uniform level of illumination throughout the room. To make the entire area equally suitable for whatever its use may be, spottiness and dark corners are eliminated so far as possible. The maximum permissible spacing between luminaires and from luminaires to side-walls for equal uniformity is a function of the mounting height above the floor and the distribution characteristics of the luminaires. Figure 8-1*a* and *b* dramatizes the effect of variations in spacing.

In general, with greater mounting height and closer spacing greater uniformity is achieved. The *variation factor* which equals the maximum illumination level divided by the average level is used as a measure of uniformity. A spacing which does not substantially exceed the mounting height above the floor usually will result in reasonably uniform illumination.

Table 8-2 gives the maximum spacing of common types of luminaires with which reasonably uniform illumination may be obtained. The distance between luminaire and side-wall should not exceed one-half the distance between luminaires. For equal uniformity where aisles or storage spaces are adjacent to walls and where desks and benches are along walls the distance between luminaires and walls should not exceed one-third to one-quarter the spacing between luminaires.

The spacing-mounting height relations apply not only to individual lumi-

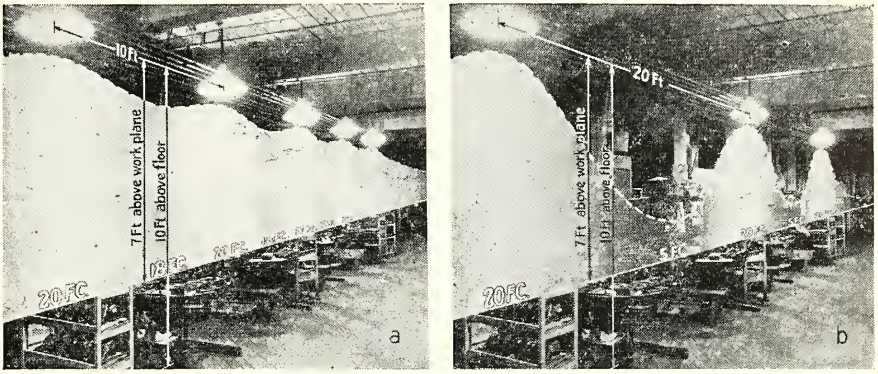


FIG. 8-1. Proper spacing of luminaires, as in a, results in uniform illumination. When luminaires are spaced too far apart, as in b, the resulting illumination is non-uniform.

naires but to the spacing between continuous sections, luminous panels, troughs, or sections of coves.

Spacing of alternate mercury and incandescent units in combination systems should provide for a fair degree of uniformity with either system used alone, as well as for overlapping and blending of the light when used in combination. An alternate staggered layout with the spacing between units not to exceed eight-tenths of the mounting height above the floor often is satisfactory.

To retain symmetry with the arrangement of bays, columns, partitions, or other architectural elements closer spacing than indicated in Table 8-2 is desirable. Closer spacing will improve uniformity and reduce shadows at any given point. A few typical layouts of luminaires are given in Fig. 8-2.[11]

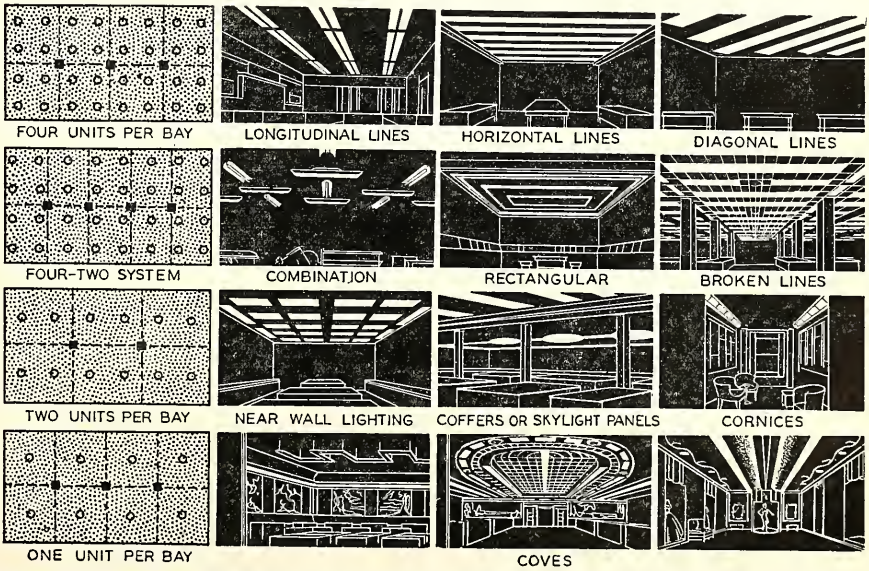
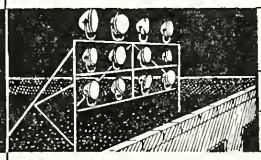
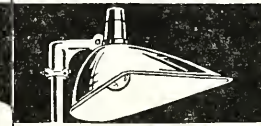


FIG. 8-2. Typical luminaire layouts in various interiors. See Section 10 for discussion.

Floodlighting Calculations

Typical floodlighting installations and equipment are shown in Fig. 8-3.

FLOODLIGHTING APPLICATIONS	TYPICAL PROJECTOR	PROJECTOR DISTANCE FROM SURFACE		LAMP	*
 BUILDINGS TWO OR THREE STORIES HIGH LIGHTED FROM POSTS AT CURB	 FLOODLIGHTS MAY BE PLACED ON CURBPOSTS OR WIDE MARQUEES TO LIGHT SMALL STORES, THEATRES, ETC., WHEN SUITABLE POSITIONS ACROSS THE STREET ARE NOT AVAILABLE.	10 – 30 FT		GS	W
 BUILDINGS LIGHTED FROM ACROSS STREET	 WHEN LENGTH OF BUILDING FACE TO BE ILLUMINATED IS NOT GREATER THAN DISTANCE OF FLOODLIGHTS FROM BUILDING, THE UNITS CAN BE PLACED IN ONE GROUP.		LIGHTED SURFACE		
		50–100 FT	LESS THAN 3,000 SQ FT	GS	M
			MORE THAN 3000 SQ FT	GS	W
		100–150 FT	LESS THAN 3,000 SQ FT	F	N
			MORE THAN 3,000 SQ FT	GS	M
		150–300 FT	LESS THAN 10,000 SQ FT	F	N
			MORE THAN 10,000 SQ FT	GS	M
 SETBACK TYPE BUILDINGS	 UNITS ARE PLACED IMMEDIATELY INSIDE AND BELOW PARAPET AND ELEVATED SUFFICIENTLY TO PERMIT EASY MAINTENANCE AND AVOID DRIFTING SNOW.	HEIGHT OF SETBACK	ONE-STORY	GS	W
			TWO-STORY	GS	M
			THREE-STORY	GS	M
			FOUR-STORY OR MORE	F	N
 COLUMNS, MONUMENTS	 BEST PROJECTOR LOCATIONS ARE MOST SATISFACTORILY DETERMINED BY TRIAL. STATUES USUALLY REQUIRE LIGHT FROM ABOVE TO AVOID GROTESQUE EFFECT UPON HUMAN FEATURES CAUSED BY LIGHT FROM BELOW.	2 – 100 FT		F	N
 SMALL OUTDOOR AREAS	 UNITS SHOULD BE MOUNTED NOT LESS THAN 20 FEET HIGH AND LOCATED WHERE THEY WILL NOT HINDER TRAFFIC OR CAUSE ACCIDENTS DUE TO GLARE	AT EDGE OF AREA		GS	W
 LARGE OUTDOOR AREAS	 TO INSURE THAT GLARING LIGHT SOURCES WILL NOT BE IN THE DIRECT LINE OF VISION, IT IS ADVISABLE TO MOUNT PROJECTORS AS HIGH AS POSSIBLE.	AT EDGE OF AREA		GS	W OR N **

* PROJECTOR BEAM SPREAD : W=WIDE, M=MEDIUM, N=NARROW
** DEPENDING ON LENGTH OF THROW
GS=GENERAL SERVICE F=FLOODLIGHTING

FIG. 8-3. Typical floodlighting applications and equipment. See Section 11 for discussion.

Coverage. Area of spot is the principal concern in checking for coverage. Length and width of spot are also given. These are found useful in problems involving the lighting of architectural details and also when it is desired to illuminate a limited area.

After projector location is determined, guidance for collecting the data essential to a coverage check is given in Fig. 8-4.

The number of projectors required for reasonably uniform coverage is obtained by dividing the total area to be lighted by the spot area of one projector.

Floodlighting installations also can be laid out to scale with a protractor, a method which provides an aiming diagram as well as coverage check, and also by other methods.[19]

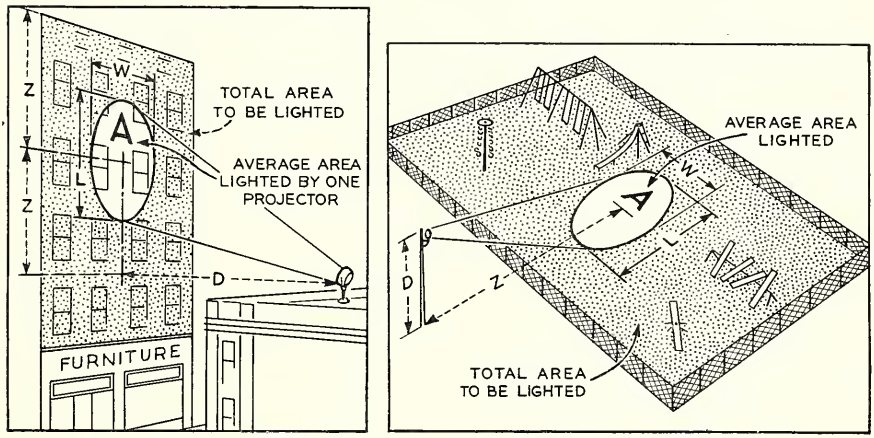


FIG. 8-4. Spot sizes (average effective coverage) for typical beam spreads and installation arrangements are given in Table 8-8. D = the distance from the projector to the plane of the lighted surface or area, measured perpendicular to the surface. Z = the measurement which determines the average angle of throw and consequently determines the average area covered by each projector. Two conditions apply: (1) If a perpendicular from the plane of the lighted surface to the projector falls *within* the total area to be lighted, Z = one half the distance from the base of the perpendicular to the farthest edge of the surface to be lighted. (2) If a perpendicular from the plane of the lighted surface to the projector falls *outside* the total area to be lighted, Z = the distance from the base of the perpendicular to the mid-point of the total area to be lighted.

Illumination. To determine the number of luminaires required to produce any desired average level of illumination over a known area, or the necessary beam lumens where the number of projectors is known, use the following formula:[12]

$$\text{Number of projectors} = \frac{E_{av} \times A}{k_m \times F_b}$$

where

E_{av} = maintained average illumination level (footcandles)

A = area of surface to be lighted (square feet)

k_m = maintenance factor (usually assumed to be 0.70)

F_b = initial lumens in the beam

Table 8-8. Dimensions and Areas of Illuminated Spots Produced by Various Types and Arrangements of Floodlights.*[12] (See Fig. 8-4.)

D†	Z†	10° BEAM			15° BEAM			20° BEAM			25° BEAM		
		Area†	Length†	Width†	Area	Length	Width	Area	Length	Width	Area	Length	Width
15	0	5	3	3	10	4	4	18	5	5	30	7	7
	10	8	4	3	20	6	5	33	8	7	50	10	8
	20	21	7	4	50	11	7	93	16	9	160	20	12
	30	52	14	6	130	21	9	250	30	13	460	41	17
	40	113	22	8	290	37	12	620	55	17	1,300	83	23
25	0	11	4	4	25	7	7	44	9	9	70	11	11
	20	23	7	5	50	11	8	100	15	12	150	19	14
	40	71	16	8	170	25	13	330	34	17	540	45	22
	60	195	31	11	490	49	18	1,030	73	25	1,960	105	34
	80	450	54	15	1,200	90	24	2,920	145	36	7,270	251	53
50	0	38	9	9	90	13	13	155	18	18	210	20	20
	20	47	11	9	110	15	14	195	21	19	320	26	24
	40	81	14	11	190	22	17	330	30	23	550	38	29
	60	150	22	14	340	33	20	630	45	28	1,070	58	36
	80	260	32	17	600	49	25	1,160	68	35	2,060	90	45
75	0	67	13	13	170	20	20	310	26	26	480	33	33
	40	110	17	14	250	25	22	440	34	30	710	43	38
	80	220	28	18	540	43	29	1,010	59	39	1,630	75	50
	120	530	48	25	1,210	74	38	2,320	102	52	3,930	135	67
	160	1,040	76	32	2,500	119	49	5,050	171	67	9,060	238	88
100	0	120	17	17	310	26	26	490	35	35	770	44	44
	40	150	20	19	390	31	28	610	41	38	980	52	48
	80	250	29	22	580	44	34	1,050	59	46	1,700	75	58
	120	470	43	28	890	66	41	2,000	90	56	3,290	116	72
	160	830	63	33	1,950	98	51	3,700	136	69	6,340	180	89
	200	1,300	80	42	—	—	—	6,650	201	84	—	—	—
150	0	270	26	26	610	39	39	1,100	53	53	1,740	67	67
	40	300	28	27	680	42	41	1,230	57	55	1,940	71	69
	80	400	34	30	900	51	45	1,630	69	60	2,580	87	76
	120	570	43	34	1,310	65	51	2,380	89	68	3,820	113	87
	160	860	57	39	1,970	86	58	3,610	117	79	5,920	151	100
	200	1,280	74	44	—	—	—	5,550	156	91	—	—	—
200	0	480	35	35	1,090	53	53	1,940	71	71	3,090	89	89
	40	510	37	36	1,160	55	54	2,080	73	72	3,286	92	91
	80	600	41	38	1,360	61	57	2,470	82	77	3,910	104	96
	120	770	48	41	1,730	72	61	3,160	97	83	5,030	123	104
	160	1,030	58	45	2,330	87	68	4,240	118	91	6,800	150	115
	200	1,370	71	50	—	—	—	5,800	146	102	—	—	—
300	0	1,080	52	52	2,460	79	79	4,400	106	106	6,940	133	133
	40	1,110	53	53	2,520	80	80	4,520	108	107	7,140	136	134
	80	1,200	56	54	2,720	85	82	4,890	114	110	7,740	143	138
	120	1,350	61	57	3,070	92	85	5,530	123	114	8,790	156	144
	160	1,580	68	60	3,590	102	90	6,480	137	120	10,300	173	152
500	0	3,010	87	87	6,810	132	132	12,200	176	176	19,300	222	222
	40	3,030	88	88	6,870	133	132	12,300	177	177	19,500	223	222
	80	3,120	90	89	7,070	135	133	12,700	181	179	20,100	228	225
	120	3,270	93	90	7,410	139	135	13,300	187	181	21,100	235	228
	160	3,490	97	92	7,900	145	138	14,200	195	185	22,500	246	233

The *beam lumens* rating of a particular luminaire is often provided by the manufacturer or may be computed from a candlepower distribution curve as follows:

1. On a form such as Table 8-9 record the following data:
 Maximum intensity, I_{max} (candlepower)
 Angle at 10 per cent I_{max} (degrees)
2. Compute beam spread:
 Spread = 2× (angle at 10 per cent I_{max}) (degrees)

Table 8-8. Continued

D	Z	30° BEAM			35° BEAM			D	Z	40° BEAM			50° BEAM		
		Area	Length	Width	Area	Length	Width			Area	Length	Width	Area	Length	Width
	0	45	8	8	60	9	9		0	80	11	11	130	14	14
	10	80	12	10	110	14	12		5	110	13	12	175	17	16
15	20	240	26	14	360	32	17	15	10	150	17	14	260	22	18
	30	790	56	21	1,430	79	27		15	310	25	19	530	33	25
	40	2,900	133	33	8,690	622	50		20	630	43	23	1,250	63	30
	—	—	—	—	—	—	—		25	1,150	65	27	—	—	—
	0	100	13	13	140	16	16		0	185	18	18	305	23	23
	10	140	16	15	170	19	17		10	240	22	20	400	28	26
	20	220	23	18	310	28	20		20	450	33	24	800	44	32
25	30	430	36	21	660	45	27	25	30	970	55	32	2,050	83	44
	40	920	59	28	1,430	75	34		40	2,300	98	42	6,950	187	66
	50	1,930	94	37	3,270	131	45		50	6,450	194	60	—	—	—
	60	3,950	155	46	8,590	249	63		—	—	—	—	—	—	—
	0	350	27	27	510	32	32		0	320	26	26	520	33	33
	20	450	33	29	650	37	34		10	380	28	27	580	37	32
50	40	800	46	35	1,160	55	41	35	20	510	35	32	890	47	39
	60	1,590	73	44	2,440	90	53		30	850	49	35	1,550	67	47
	80	3,200	117	56	5,300	151	69		40	1,490	71	43	3,000	105	59
	—	—	—	—	—	—	—		50	2,700	106	52	—	—	—
	0	700	40	40	970	47	47		0	470	33	33	780	42	42
	20	790	43	42	1,070	51	49		10	520	35	34	820	44	42
	40	1,060	53	46	1,460	63	54		20	650	40	37	1,070	52	47
75	60	1,590	69	53	2,200	83	61	45	30	890	49	42	1,550	67	53
	80	2,480	93	61	3,620	114	73		40	1,320	66	46	2,460	91	62
	100	4,000	128	72	5,780	160	84		50	2,100	87	55	—	—	—
	120	6,400	175	84	10,100	226	103		—	—	—	—	—	—	—
	0	1,130	54	54	1,560	63	63		0	640	40	40	1,030	51	51
	40	1,430	63	58	1,980	74	68		20	790	46	44	1,300	59	56
100	80	2,550	92	70	3,560	110	82	55	40	1,320	66	51	2,330	88	68
	120	5,050	146	89	7,510	180	106		60	2,650	104	65	5,250	152	88
	160	10,300	234	112	—	—	—		80	5,600	172	83	—	—	—
	0	1,760	67	67	2,440	79	79		0	1,020	51	51	1,680	65	65
	40	2,130	73	71	2,870	88	83		20	1,180	55	54	1,940	72	69
125	80	3,090	97	80	4,350	116	96	70	40	1,680	71	60	2,860	93	78
	120	5,200	138	96	7,430	167	113		60	2,700	98	70	5,000	135	94
	160	9,140	200	116	—	—	—		80	4,700	142	84	—	—	—
	0	2,540	80	80	3,510	95	95		0	1,500	62	62	2,460	79	79
	40	2,880	86	85	3,900	102	97		20	1,680	67	64	2,750	85	82
150	80	3,820	105	92	5,300	125	108	85	40	2,130	78	69	3,600	102	90
	120	5,700	135	107	8,000	166	123		60	3,080	100	78	5,400	133	103
	160	10,300	234	112	—	—	—		80	4,750	132	92	—	—	—
	—	—	—	—	—	—	—		100	7,500	181	106	—	—	—
	0	4,500	107	107	6,250	126	126		0	2,100	73	73	3,400	93	93
	40	4,800	111	109	6,660	132	129		20	2,280	78	74	3,700	98	96
200	80	5,700	125	116	7,950	149	136	100	40	2,700	86	79	4,500	112	102
	120	7,500	150	127	10,300	178	148		60	3,500	104	87	7,800	138	113
	160	10,200	184	141	—	—	—		80	5,000	130	98	—	—	—
	—	—	—	—	—	—	—		100	7,300	168	110	—	—	—

* Allowance made for necessary beam overlap.
† Dimensions may be in feet and square feet or in other units if more convenient.

3. Record (on Table 8-9) constants from Appendix Table A-31 page A-47, for not less than ten zones equal in width to about one tenth the beam spread. Measure or estimate and record on Table 8-9 the average candlepower for each zone.

4. Compute zonal lumens F_z:

$$F_z = I_{z_{av}} \times \text{zonal constant.}$$

The sum of the zonal lumens in each zone from 0 degree to the angle at 10 per cent I_{max} equals the beam lumens.

Table 8-9. Form for Use in Calculating Beam Lumens in Floodlights, Spotlights,* and Searchlights.*

Maximum intensity candlepower
Angle at 10-per-cent maximum intensity degrees
Beam spread = 2 × (angle at 10-per-cent I_{max}) = ... degrees

ZONES*	I_{av} IN ZONE†		ZONAL CONSTANT‡§		F_z (ZONAL LUMENS)
1.°°		×		=	
2.°°		×		=	
3.°°		×		=	
4.°°		×		=	
5.°°		×		=	
6.°°		×		=	
7.°°		×		=	
8.°°		×		=	
9.°°		×		=	
10.°°		×		=	

Note. Lumens in the beam (F_b) equal the sum of the zonal lumens in the zones between 0 degree and angle at 0.1 I_{max}. $F_b = \Sigma_0^{0.1} I_{max} F_z$ = ...

* If the beam is very narrow (as in searchlights) this computation is made by summing up the lumens in a group of rectangular solid angles enclosed by the beam. Average candlepower measurements at the center of rectangular areas subtending not less than one tenth the beam spread in horizontal and vertical directions are used. The total number of solid angles used is 100, for which the constants are found in Appendix Table 000.

† From distribution curve or measurements.

‡ Zone width should not exceed one tenth the beam spread for best results.

§ From Appendix Table 31, page A-47.

Searchlighting Calculations

Lumens in searchlight beams may be estimated in the manner just described for floodlights.

The illumination on a circular area in a searchlight beam may be determined by dividing the area by the lumens in the zones subtended by the area, and multiplying by the atmospheric transmittance.

The *useful range of searchlights* can be calculated with the aid of the following formulas:

$$E_a = E_b \frac{t^{d_1+d_2} K}{d_1^2} \text{ or } E_a = E_b \frac{t^{2R} K}{R^2}$$

where

E_a = necessary illumination at observer's position for viewing object
E_b = actual illumination at 1 mile
t = atmospheric transmittance (0.6 per mile for average clear weather)
d_1 = max distance, searchlight to visible object
d_2 = max distance object visible to observer
K = reflectance of object
R = useful range of searchlight beam

Show-Window Lighting

For estimating average illumination in show windows, two planes are frequently used to represent the average display surfaces as shown in Fig. 8-5. These vary in size and position in different windows. They are divided into zones A, B, and C to permit designing for either a variation in illumination level between parts of the display or for a uniform level equally effective throughout.

Footcandles produced at different distances by projector and reflector lamps are given in Fig. 8-6.[11]

In selecting a zone for use in estimating average illumination, consider the nature of the trim and whether the back will be open or closed (see Store Lighting, Section 10) and proceed as follows:

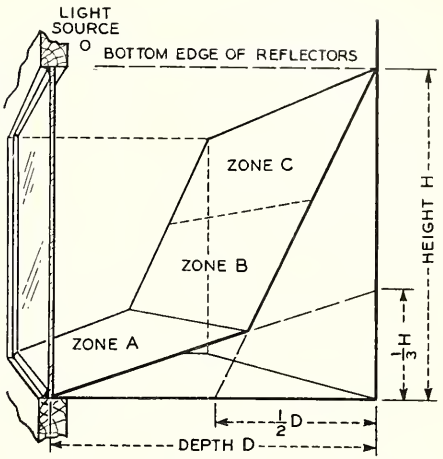


FIG. 8-5. Show windows are divided into three zones (A, B, and C) when it is desired to estimate the number of lamps necessary for a given illumination level.

1. Record the dimensions H, D, L, and the desired average illumination, E_{av}.

2. Compute the following ratios: $\dfrac{\text{Height (to bottom of luminaire)}}{\text{Depth}} = \dfrac{H}{D}$

$$\frac{\text{Length}}{\text{Height}} = \frac{L}{H}$$

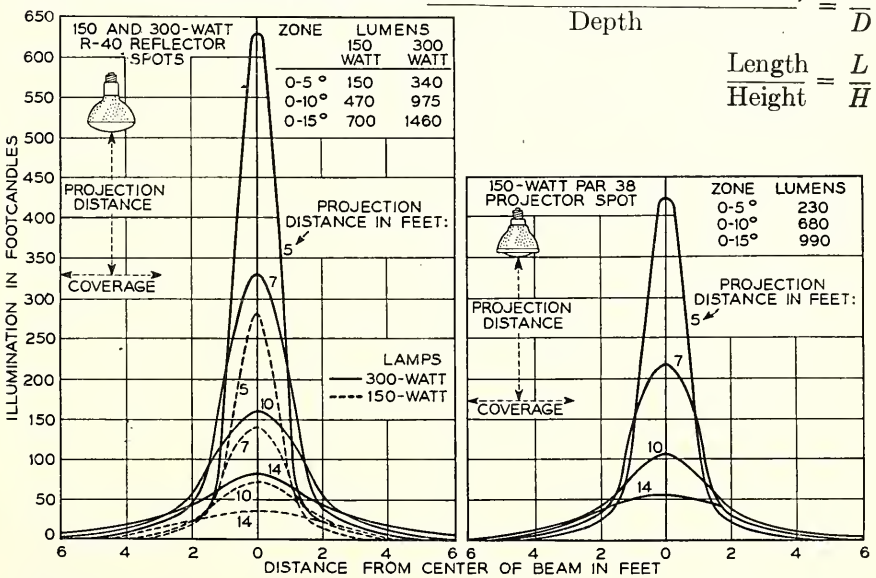


FIG. 8-6. Illumination produced at various distances by typical reflector and projector lamps.

3. From Table 8-10 obtain *multiplying* (K), *length* (L), and *shielding* (S) factors.

4. The *initial lumens* to be provided per linear foot of window:

$$F_f = E_{av} HKLS$$

where E_{av} = average illumination maintained in service (assuming maintenance factor = 0.75)

H = height in feet

K = multiplying factor

L = length factor

S = shielding factor

Necessary initial lumens per incandescent lamp

$$= \frac{F_f \times \text{lamp spacing (inches)}}{12}$$

Necessary feet of fluorescent lamps

$$= \frac{F_f}{\text{initial lumens per foot of lamps}} \times \text{window length}$$

Table 8-10. Constants for Use in Calculating Average Maintained Illumination in Typical Show Windows[*20]

A. MULTIPLYING FACTOR K FOR INCANDESCENT LUMINAIRES†

H/D Ratio	ZONE A			ZONE B			ZONE C			OVER-ALL		
	Wide	Semi-conc.	Conc.	Wide	Semi-conc.	Conc.	Wide	Semi-conc.	Conc.	Wide	Semi-conc.	Conc.
4.0	4.2	3.4	2.0	6.8	5.5	3.9	1.6	2.0	3.0	2.8	3.4	2.9
3.5	3.6	3.0	1.8	6.0	5.0	4.1	1.8	2.3	3.6	2.9	3.1	3.0
3.0	3.2	2.6	1.7	5.5	4.6	4.5	2.0	2.8	4.1	3.0	3.2	3.1
2.5	3.0	2.4	1.7	4.6	4.0	5.0	2.4	3.7	5.0	3.1	3.3	3.2
2.0	2.9	2.3	1.7	4.3	3.7	5.5	3.1	5.1	6.1	3.3	3.4	3.4
1.5	3.0	2.4	1.9	4.1	3.6	6.3	4.1	8.3	9.4	3.6	3.6	3.6
1.0	3.3	2.9	2.3	4.6	4.1	7.5	7.5	20.3	20.0	4.4	4.3	4.3

B. MULTIPLYING FACTOR K FOR FLUORESCENT LUMINAIRES‡§

H/D Ratio	ZONE A			ZONE B			ZONE C			OVER-ALL		
	Wide	Semi-conc.	Conc.	Wide	Semi-conc.	Conc.	Wide	Semi-conc.	Conc.	Wide	Semi-conc.	Conc.
4.0	4.9	5.7	4.2	11.3	10.3	7.6	2.7	1.5	1.7	3.8	3.0	2.7
3.5	4.6	5.2	3.9	9.2	9.2	6.8	2.3	1.6	1.9	3.8	3.1	2.8
3.0	4.2	4.2	3.4	7.9	6.9	5.6	2.5	1.8	2.2	4.0	3.1	2.9
2.5	4.1	3.9	3.0	6.2	5.0	4.7	2.8	2.2	2.7	4.0	3.3	3.1
2.0	4.1	3.8	2.7	5.7	4.3	3.7	3.3	2.8	3.7	4.1	3.5	3.3
1.5	4.0	3.6	2.4	5.2	4.4	4.1	4.3	4.1	5.7	4.5	4.0	3.6
1.0	4.3	3.6	2.3	5.0	5.0	6.8	7.6	7.6	15.1	5.3	4.7	4.2

Table 8-10. Continued

C. LENGTH FACTOR L FOR INCANDESCENT LUMINAIRES

TYPE OF EQUIPMENT §	LENGTH OF WINDOW DIVIDED BY HEIGHT (L/H)							
	0.5		1.0		1.5		2.0	
	1 Glass end	Solid ends	1 Glass end	Solid ends	1 Glass end	Solid ends	1 Glass end	Solid ends
Wide	1.40	1.25	1.10	1.05	1.00	1.00	1.00	0.95
Semi-Conc.	1.30	1.20	1.05	1.00	1.00	1.00	1.00	0.95
Conc.	1.20	1.10	1.00	1.00	1.00	1.00	1.00	1.00

D. LENGTH FACTORS L FOR FLUORESCENT LUMINAIRES

LENGTH OF WINDOW DIVIDED BY HEIGHT (L/H)								
0.5		1.0		1.5		2.0		
1 Glass end	Solid ends	1 Glass end	Solid ends	1 Glass end	Solid ends	1 Glass end	Solid ends	
1.55	1.45	1.20	1.10	1.00	0.95	0.95	0.90	

E. SHIELDING FACTOR S FOR INCANDESCENT LUMINAIRES‖

H/D Ratio	LOUVERS AT RIGHT ANGLES TO PLATE GLASS			LOUVERS PARALLEL TO PLATE GLASS			ECCENTRIC RING LOUVERS		
	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C
4.0	1.3	1.4	1.4	1.2	1.4	2.2	Not usually employed		
3.5	1.3	1.4	1.4	1.2	1.4	2.3	Not usually employed		
3.0	1.3	1.4	1.5	1.2	1.5	2.6	Not usually employed		
2.5	1.3	1.4	1.6	1.2	1.6	3.0	Not usually employed		
2.0	1.4	1.4	1.6	1.2	1.8	3.7	1.4	1.6	2.9
1.5	1.4	1.5	1.7	1.2	1.9	4.6	1.4	1.8	3.3
1.0	1.4	1.5	1.8	1.3	2.1	5.3	1.4	2.2	4.0

F. SHIELDING FACTOR S FOR FLUORESCENT LUMINAIRES‖

H/D RATIO	SHIELDING FACTOR S		
	Egg-crate Louvers (Mat White) Shielding Lamps to 45° Crosswise and 25° Lengthwise		
	Zone A	Zone B	Zone C
4.0	1.11	1.20	1.14
3.5	1.11	1.20	1.14
3.0	1.11	1.18	1.14
2.5	1.11	1.18	1.14
2.0	1.11	1.18	1.16
1.5	1.09	1.15	1.19
1.0	1.09	1.10	1.27

* Maintenance factor used = 0 75.
† Table based on typical commercial equipment.
‡ This table is based on the coefficients of utilization for four rows of fluorescent lamps in reflectors of typical widths, at typical angles of tilt. If other numbers of rows and different widths of unit or other angles of tilt are employed, some differences in results are to be expected. These may be greatest when the rearmost of the multiple rows approach zone C.
§ Output: wide 65 per cent; semiconcentrating 85 per cent; concentrating 80 per cent.
‖ Factor for unshielded lamps = 1.00.

Showcase Lighting

Typical arbitrary trim lines used for showcase lighting calculations are the same as those shown in Fig. 8-5 for show windows. Plane A extends from the lower front edge of the case to a point one-third of the case height above the base. Plane C-B runs from the top back corner to a point that is one-half case depth. Zones B and C are equal in area. One, two, or perhaps all three zones will be important depending on the method of displaying the merchandise.

To estimate the average *initial* illumination on a zone in one of the cases, substitute the proper value for the utilization factor K_u in the following formula:

$$\text{Footcandles on zone} = K_u \times F_f \,^{20}$$

where

F_f = lumens per foot of case length
K_u = utilization factor from Table 8-11.

The value of F_f for either filament or fluorescent lamps will be:

$$F_f = \frac{F\ell \times N}{L}$$

where

$F\ell$ = initial lumen output of each lamp
N = number of lamps
L = length of case (feet)

Table 8-11. Utilization Factors, K_u, for Typical 20-Inch Showcase, 10, 20, or 27 Inches High.[20]

ZONE	FLUORESCENT LAMP IN WHITE DIFFUSING REFLECTOR	FLUORESCENT LAMP IN CONCENTRATING REFLECTOR	INCANDESCENT LAMP, CLEAR T-10 IN SEMI-DIFFUSING REFLECTOR	INCANDESCENT LAMP T-10 REFLECTOR SHOWCASE	HEIGHT (inches)
A	0.266	0.321	0.219	0.356	
B	.122	.198	.137	.359	10
C	.051	.093	.095	.128	
A	.170	.165	.143	.226	
B	.137	.192	.119	.333	20
C	.081	.139	.122	.184	
A	.129	.123	.108	.179	
B	.112	.145	.093	.238	27
C	.094	.150	.121	.207	

Shelf and Garment Case Lighting

To aid in estimating the average initial illumination normal to the vertical surface representing the plane of the merchandise in shelves or garment cases lighted by a continuous row of fluorescent lamps, the surface may be divided into 6-inch sections as shown in Fig. 8-7.

The initial footcandles normal to any 6-inch section can be computed by substituting values in the following equation:

$$\text{Footcandles} = K_u F_f$$

where K_u = utilization factor (Fig. 8-7)

F_f = lumens-per-foot rating of the lamps used.[20]

Two values of K_u for the centerpoint of each 6-inch section are given in Fig. 8-7 for merchandise plane depths of 3 inches, 6 inches, 9 inches, 12 inches, and 18 inches. The upper of each pair of figures is the factor for a continuous row of fluorescent lamps shielded by a cornice painted white underneath. The lower figures are for the same lamps, fitted with a concentrating reflector aimed at the bottom of the vertical plane assumed to be 4 feet high. Where the height is less than 4 feet, the reflector would be aimed higher and some increase in the footcandle values would result.

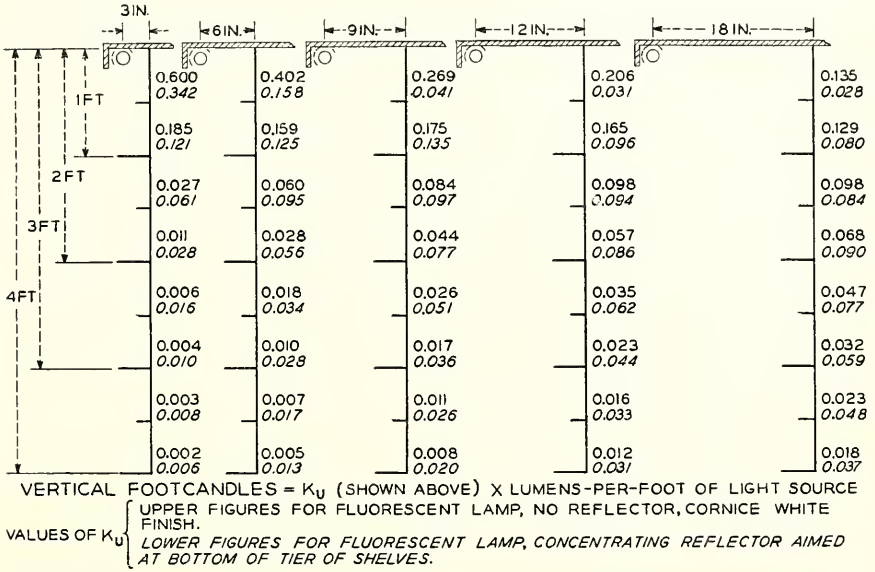


FIG. 8-7. Multiplying factors K_u used in computing the illumination (normal to a vertical surface representing the merchandise on shelves or in garment cases) produced by a continuous row of fluorescent lamps. Lower figures are for installations including a concentrating reflector; upper figures for installations without reflector.

Luminous Elements

The efficiencies of a number of typical luminous elements are given in Table 8-12. The maintained average brightness of a specific element may be obtained from the following formula:

$$B_{av} = \frac{EF\ell NK_m}{A}$$

where

B_{av} = maintained average brightness of element (footlamberts)
E = efficiency of element (from Table 8-12) (per cent)
$F\ell$ = initial lumen output per lamp
N = number of lamps
K_m = maintenance factor
A = luminous area (square feet)

Values computed with this formula, assuming a maintenance factor of 0.70, are given in Table 8-13.

Table 8-12. Efficiencies of Various Forms of Luminous Elements[12]

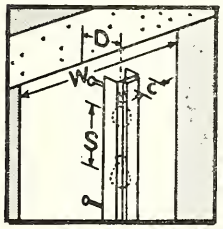
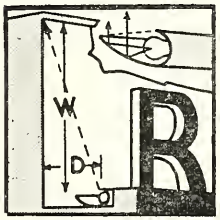
TYPE OF ELEMENT	DIMENSIONAL RATIOS	REFLECTANCE OR TRANSMITTANCE						
		0.20	0.30	0.40	0.50	0.60	0.70	0.80
		Element Efficiency (%)						
	D = 0.33 W S = 0.50 W S = 1.5 D A = (W − C) S	8	12	16	20	24	28	32
		Width based on 5 to 1 variation of brightness from center to edge. Concavity of surface produces greater uniformity of brightness; convexity increases shading. In design of cross-section, trough cutoff and angle of view are very important.						
	D = 0.25 W S = 0.56 W S = 2.25 D A = WS	7	10	13	17	20	23	27
		Requires polished metal parabolic trough reflectors with maximum candlepower directed to the far edge of surface. With ratios given brightness graduations will be of the order of 25 to 1; the degree of shading can be lessened by the use of a larger, more concentrating reflector, and by increasing D with respect to W.						

Table 8-12. Continued

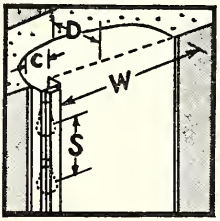
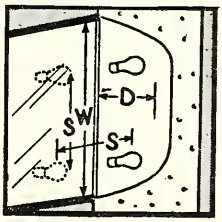
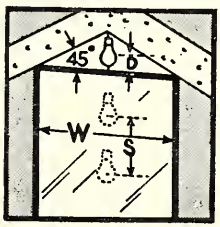
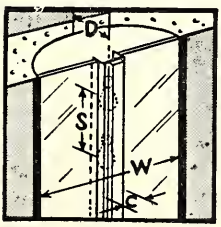
TYPE OF ELEMENT	DIMENSIONAL RATIOS	REFLECTANCE OR TRANSMITTANCE
		0.20 \| 0.30 \| 0.40 \| 0.50 \| 0.60 \| 0.70 \| 0.80
		Element Efficiency (%)
	D = 0.33 W S = 0.33 W S = D A = (W − C) S	7 \| 10 \| 13 \| 17 \| 20 \| 23 \| 27 Slightly graduated brightness produced by lamps at one side; uniformity if lamps are located on each side with a ratio as given. In small elements make certain that dimensions allow for easy lamp replacement.
	(For 2 rows of lamps) D = 0.33 W S = 0.50 W S = 1.5 D A = 0.50 WS	25 \| 35 \| 44 \| 51 \| 56 \| 61 \| 65 Representative of a great variety of forms ranging from a narrow band requiring a single row of lamps to large expanses of luminous glass areas requiring a wide variety of lamp arrangements. Efficiencies vary slightly with size and form, but spacing between lamps should conform to the cavity depth and type of translucent material used.
	D = 0.40 W S = 0.60 W S = 1.5 D A = WS	26 \| 37 \| 46 \| 54 \| 60 \| 66 \| 70 Lamps should be placed in the corner to permit wider spacing and better lateral uniformity of brightness with highly diffusing materials. A slight shading of brightness at the sides may be noticed. In small elements tubular or Lumiline lamps placed end to end conserve space.
	D = 0.33 W S = 0.66 W S = 2 D A = (W − C) S	13 \| 17 \| 21 \| 25 \| 29 \| 33 \| 37 Indirectly lighted transilluminated elements of this character may use any type of translucent material, the choice being governed by the unlighted appearance, texture, and efficiency.

Table 8-12. Continued

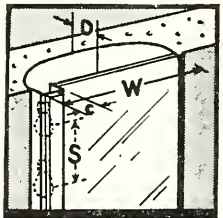
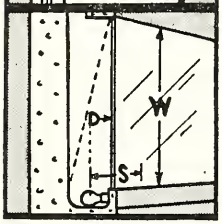
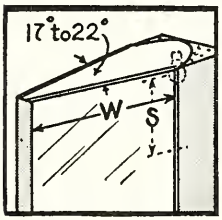
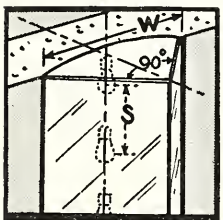
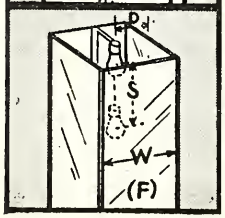
TYPE OF ELEMENT	DIMENSIONAL RATIOS	REFLECTANCE OR TRANSMITTANCE
		0.20 \| 0.30 \| 0.40 \| 0.50 \| 0.60 \| 0.70 \| 0.80
		Element Efficiency (%)
	D = 0.17 W S = 0.30 W S = 1.8 D A = (W − C) S	8 \| 12 \| 15 \| 17 \| 19 \| 20 \| 21 A graduated brightness will be obtained by a single trough located on one side; uniformity if lamps are placed at each side with the ratios as given.
	D = 0.10 W S = 0.20 W S = D A = WS	13 \| 20 \| 26 \| 31 \| 35 \| 38 \| 40 With highly diffusing translucent materials, the contour of the reflecting background is unimportant. With less diffusing materials, the shape affects the graduation of brightness as does the angle of view.
	S = 0.40 W A = 2 WS	24 \| 35 \| 45 \| 51 \| — \| — \| — Wedge-type elements use a polished aluminum parabolic trough reflector with lamps centered at focus. The slight graduation of brightness (approximately 2 to 1) with cased opal glass sides maintains an effective luminous background for sign letters or decorative patterns.
	D = 0.36 W S = 0.54 W A = 1.43 WS	33 \| 45 \| 55 \| 65 \| 73 \| 79 \| 83 Lamps should be centered on a line equidistant from both sides; in larger units the shallow cavity may be eliminated.
	D = 0.50 W S = 0.75 W A = 3 WS	41 \| 55 \| 66 \| 74 \| 80 \| 84 \| 86 Lamps should be centered in the square cross section. Efficiencies apply to the complete element but the face (F) will be about 25 per cent brighter than the sides when highly diffusing material is used.

Table 8-13. Maintained Average Brightness of Various Luminous Elements Computed for Different Efficiencies, Areas, and Lamp Lumen Ratings. (Maintenance Factor Assumed to be 0.70.)[12]

LUMINOUS AREA PER LAMP (Square Inches)	LAMP		ELEMENT EFFICIENCY (PER CENT)						
	Watts*	Lumens	20	30	40	50	60	70	80
			Footlamberts						
100	10	78	16	24	31	39	47	55	63
	15	140	28	42	56	71	85	99	113
	25	258	52	78	104	130	156	182	208
	40	440	89	133	177	222	266	310	355
	60	762	154	230	307	384	461	538	614
	75	1,065	215	322	429	537	644	751	859
	100	1,530	308	463	617	771	925	1,080	1,234
200	25	258	26	39	52	65	78	91	104
	40	440	44	67	89	111	133	155	177
	60	762	77	115	154	192	230	269	307
	75	1,065	107	161	215	268	322	376	429
	100	1,530	154	231	308	386	463	540	617
	150	2,535	256	383	511	639	767	894	1,022
	200	3,400	343	514	685	857	1,028	1,200	1,371
300	40	440	30	44	59	74	89	103	118
	60	762	51	77	102	128	154	179	205
	75	1,065	72	107	143	179	215	250	286
	100	1,530	103	154	206	257	308	360	411
	150	2,535	170	256	341	426	511	596	681
	200	3,400	228	343	457	571	685	800	914
500	60	762	31	46	61	77	92	108	123
	75	1,065	43	64	86	107	129	150	172
	100	1,530	62	93	123	154	185	216	247
	150	2,535	102	153	204	256	307	358	409
	200	3,400	137	206	274	343	411	480	548
	300	5,520	223	334	445	556	668	779	890
	500	9,800	395	593	790	988	1,185	1,383	1,581
700	60	762	22	33	44	55	66	77	88
	75	1,065	31	46	61	77	92	107	123
	100	1,530	44	66	88	110	132	154	176
	150	2,535	73	110	146	183	219	256	292
	200	3,400	98	147	196	245	294	343	392
	300	5,520	159	238	318	397	477	556	636
	500	9,800	282	423	564	706	847	988	1,129
900	60	762	17	26	34	43	51	60	68
	75	1,065	24	36	48	60	72	83	95
	100	1,530	34	51	69	86	103	120	137
	150	2,535	57	85	114	142	170	199	227
	200	3,400	76	114	152	190	228	267	305
	300	5,520	124	185	247	309	371	433	495
	500	9,800	220	329	439	549	659	768	878
	750	14,550	326	489	652	815	978	1,141	1,304
1,500	100	1,530	21	31	41	51	62	72	82
	150	2,535	34	51	68	85	102	119	136
	200	3,400	46	69	91	114	137	160	183
	300	5,520	74	111	148	185	223	260	297
	500	9,800	132	198	263	329	395	461	527
	750	14,550	196	293	391	489	587	684	782
	1,000	20,700	278	417	556	696	835	974	1,113

* Incandescent lamp watts.

Illumination at a Specific Location

The methods described for determining average illumination in large areas do not give accurate values at specific locations. If it is desired to know the illumination at specific points, calculations are made "point-by-point."

Calculations with point sources. To determine the illumination at definite points in installations where (1) there is little reflection of light from the surroundings, and (2) where the distance from the source is large compared to the source size, variations of the inverse square law are used in all point-by-point calculations involving relatively small sources. In such situations the illumination is proportional to the intensity of the source and inversely proportional to the square of the distance from the source:[14, 15, 16]

$$E_n = \frac{I}{D^2}$$

where E_n = the illumination normal to the light rays(footcandles)
I = intensity (candlepower)
D = the distance (feet)

See Fig. 8-8a. When the distance from the source to the point of measurement is at least five times the maximum dimension of the source, the inverse square law ordinarily can be used with acceptable accuracy.

The deviation from the inverse square law produced by large sources is discussed on pages 8-41 and 8-44.

Lambert's cosine law of illumination. If the surface on which the illumination to be determined is tilted, instead of normal to the rays, the light will be spread over a greater area, reducing the illumination in the ratio of the area of plane A to the area of plane B, as shown in Fig. 8-8b. This ratio is equal to the cosine of the angle of incidence or tilt and:

$$E = \frac{I}{D^2} \cos \theta$$

where θ = angle of incidence

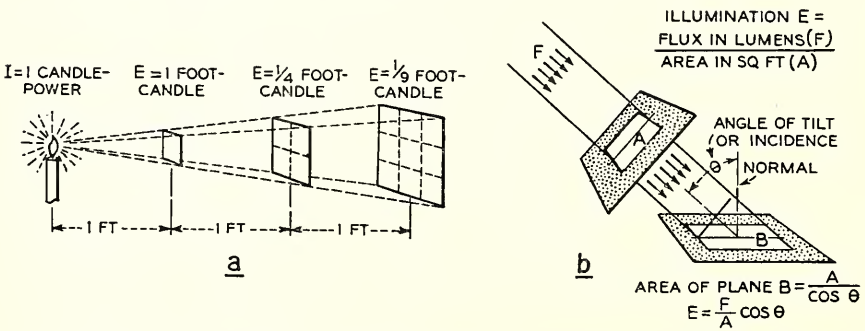


FIG. 8-8. Point-by-point calculations assume a point source and involve applications of the inverse square and cosine laws.

Referring to Fig. 8-9, E_n is the illumination at point p on a plane *normal* to the ray from the light source; E_h is the illumination at point p on a *horizontal* surface; E_v is the illumination at point p on a *vertical* surface; h is the vertical mounting height of the light source above the point p; l is the horizontal distance from the light source to the point p; d is the actual distance from the light source to the point p; I_p is the candlepower of the light source in the direction of the point p (from the distribution curve). θ_h is the angle of incidence for horizontal illumination, θ_v is the angle of incidence for vertical illumination. Where h and l are known, the angle of incidence may be obtained from the nomogram, Appendix Fig. A-2.

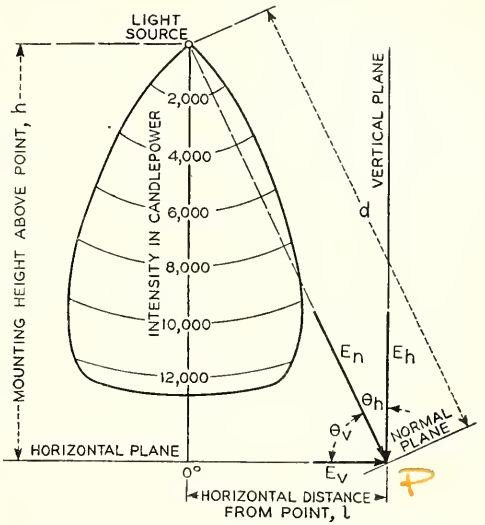


FIG. 8-9. Diagram for point-by-point calculations showing candlepower distribution curve and other variables.

The equations may be expressed in terms of either h or d:[21]

$$E_n = \frac{I}{h^2}\cos^2\theta_h = \frac{I}{d^2} \qquad d = \frac{h}{\text{Cos }\theta_h}$$

$$E_h = \frac{I}{h^2}\cos^3\theta_h = \frac{I}{d^2}\cos\theta_h \qquad \text{Cos }\theta_v = \sin\theta_h$$

$$E_v = \frac{I}{h^2}\cos^2\theta_h \sin\theta_h = \frac{I}{d^2}\sin^3\theta_h = \frac{I}{d^2}\cos\theta_v$$

To determine the cumulative horizontal illumination at point p from several contributing luminaires, it is desirable to proceed along a definite pattern.[22] Table 8-14 is a convenient form for point-by-point calculations; the candlepower values shown are initial values from Fig. 8-9. Although the illustrations used are for horizontal planes, the same procedure may be used for calculating illumination on a vertical plane by using values of d, h, and θ obtained by rotating the candlepower distribution curve in Fig. 8-9, 90 degrees in a clockwise direction.

It is more convenient to obtain the illumination from tables. In table 8-15, footcandles on a horizontal plane have been calculated from the formula

$$E_h = \frac{I}{d^2}\ \text{Cos }\theta_h$$

Conversion charts can also be employed,[23]

Asymmetrical distribution. When point-by-point calculations are to be made for luminaires having an asymmetric candlepower distribution, a group of distribution curves must be available. A practical way of presenting a group of curves for a typical asymmetrical luminaire is shown in Fig. 8-10.

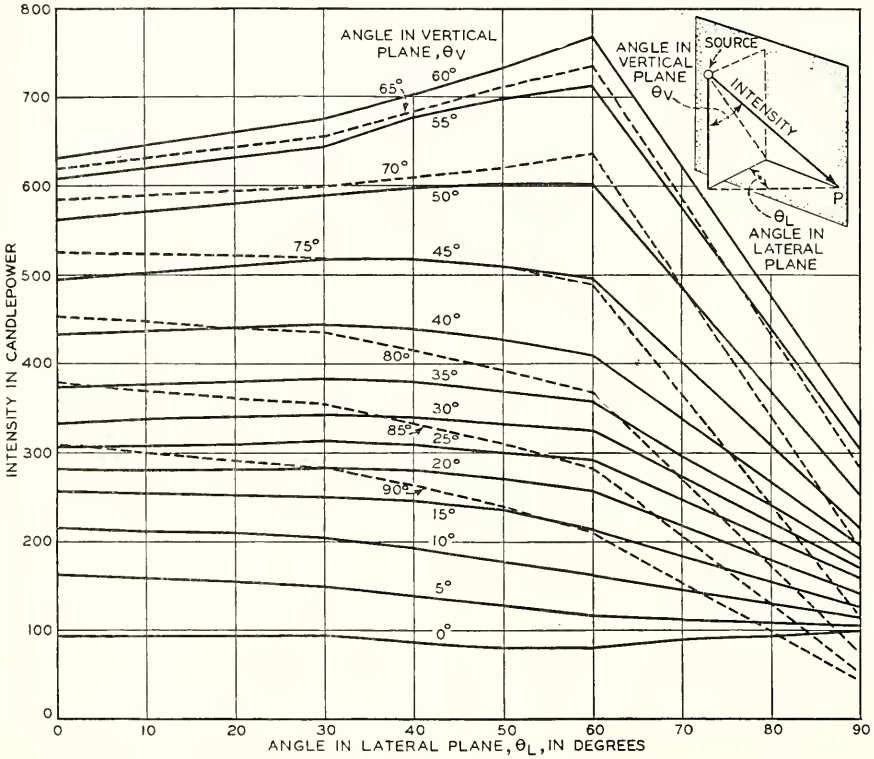


FIG. 8-10. Candlepower at various vertical and horizontal angles from a luminaire with asymmetric distribution.

Table 8-14. Form for Point-by-Point Calculations of Initial Illumination at Several Points Along a Horizontal Plane

1	h	$\frac{1}{h}$	θ*	cp†	$\cos^3\theta$‡	$cp \times \cos^3\theta$	h^2	E_h
0	30	0	0	12,600	1.00	12,600	900	14.0
5	30	0.167	9.5	12,600	0.960	12,100	900	13.5
10	30	0.333	18.4	11,800	0.856	10,100	900	11.2
15	30	0.500	26.6	8,600	0.718	6,180	900	6.9
20	30	0.666	33.7	5,000	0.576	2,880	900	3.2
25	30	0.834	40.0	2,000	0.450	900	900	1.0
30	30	1.00	45.0	1,700	0.355	602	900	0.67
35	30	1.16	49.3	1,300	0.275	360	900	0.40
40	30	1.33	53.1	800	0.215	172	900	0.19
45	30	1.50	56.4	600	0.170	102	900	0.11

* From Appendix Figure A-2, page A-45.
† From Fig. 8-9.
‡ From Appendix Table 25, page A-39.

Calculations with line sources.[25] For a perfectly diffusing line source, the candlepower at any angle in the plane containing the source axis is approximately equal to the maximum candlepower times the cosine of the angle. This relationship is reasonably accurate for fluorescent lamps and other sources where the diameters are small compared to the length.

The formulas most frequently used for calculations involving a perfectly diffusing line source are:

$$F = \pi^2 I_{max}$$

where F = flux (lumens) emitted per unit length
I_{max} = maximum candlepower

and

$$E = \frac{F}{2d} = \frac{B \times A}{2d}$$

where E = illumination on a plane parallel to the source
d = distance from source to plane (feet)
B = brightness (footlamberts)
F = total flux (lumens)
A = area (square feet)

The lumen output of fluorescent lamps divided by the maximum candlepower is somewhat lower than π^2 because the emission is not completely diffuse. For 15- to 100-watt preheat-starting fluorescent lamps the range is 9.15 to 9.30, with an average value of 9.25.[25]

It will be noted that the illumination from a line source of infinite length varies inversely as the distance but *not* inversely as the square of the distance. Figure 8-12 illustrates the relationship for a 4-foot line source.[2]

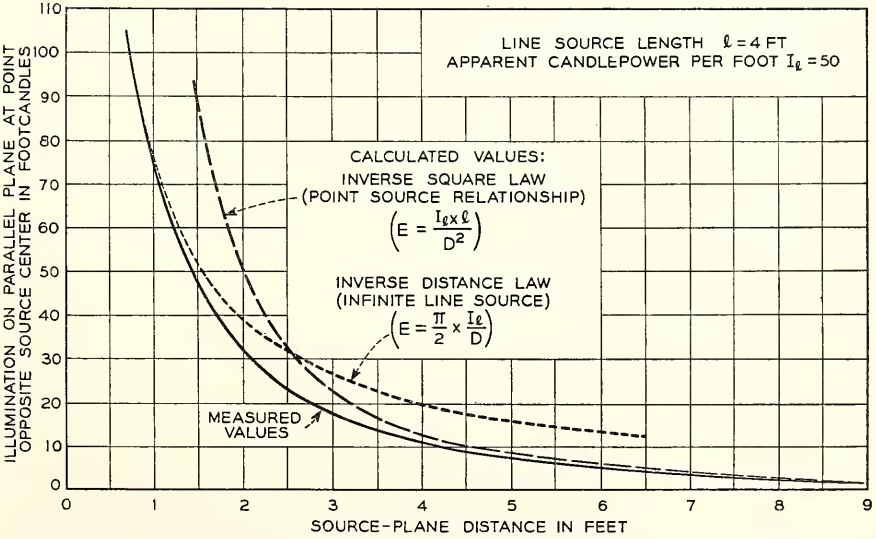


FIG. 8-11. Average illumination produced on parallel planes at various distances from a diffuse line source of a length equal to or greater than the distance varies inversely as the distance. As the distance exceeds the length of the source, the relationship approaches the inverse-square-law condition characteristic of point sources.

Table 8-15. Initial Illumination Computed for Points at Various Locations on a Horizontal Plane in Terms of 100 and 100,000 Candlepower Sources*[12]

100 CANDLEPOWER SOURCE

HORIZONTAL DISTANCE FROM UNIT (feet)

HEIGHT OF LIGHT SOURCE ABOVE SURFACE TO BE LIGHTED—FEET	0	1	2	3	4	5	6	7	8	9	10	15	20	30
4	0°0′ 6.250	14° 5.707	27° 4.472	37° 3.200	45° 2.210	51° 1.524	56° 1.066	60° .764	63° .559	66° .419	68° .320	75° .107	79° .047	82° .015
5	0°0′ 4.000	11° 3.771	22° 3.202	31° 2.522	39° 1.904	45° 1.414	50° 1.050	54° .785	58° .595	61° .458	63° .358	72° .126	76° .057	81° .017
6	0°0′ 2.778	9° 2.673	18° 2.372	27° 1.987	34° 1.600	40° 1.260	45° .982	49° .766	53° .600	56° .474	59° .378	68° .142	73° .066	79° .021
7	0°0′ 2.041	8° 1.980	16° 1.814	23° 1.585	30° 1.336	36° 1.100	41° .893	45° .722	49° .583	52° .473	55° .385	65° .154	71° .074	77° .024
8	0°0′ 1.563	7° 1.527	14° 1.427	21° 1.283	27° 1.118	32° .953	37° .800	41° .640	45° .552	48° .458	51° .381	62° .163	68° .080	75° .026
9	0°0′ 1.235	6° 1.212	13° 1.148	18° 1.054	24° .947	29° .825	34° .711	38° .607	42° .515	45° .437	48° .370	59° .168	66° .085	73° .029
10	0°0′ 1.000	5°43′ .985	11° .943	17° .879	22° .803	27° .716	31° .631	35° .550	39° .476	42° .411	45° .354	56° .171	63° .089	72° .032
12	0°0′ .694	4°46′ .687	9° .668	14° .634	18° .593	23° .546	27° .497	30° .448	34° .400	37° .355	40° .315	51° .169	59° .094	68° .036
14	0°0′ .510	4°5′ .506	8° .495	12° .477	16° .454	20° .426	23° .396	27° .365	30° .334	33° .305	36° .275	47° .162	55° .096	65° .039
16	0°0′ .391	3°35′ .388	7° .382	11° .371	14° .357	17° .339	21° .321	24° .300	27° .280	29° .259	32° .238	43° .152	51° .095	62° .041
18	0°0′ .309	3°11′ .307	6° .303	9° .297	13° .287	16° .276	18° .264	21° .250	24° .236	27° .221	29° .206	40° .140	48° .092	59° .042
20	0°0′ .250	2°51′ .249	5°43′ .246	9° .242	11° .236	14° .228	17° .219	19° .210	22° .200	24° .190	27° .179	37° .128	45° .088	56° .043
22	0°0′ .207	2°36′ .206	5°10′ .205	8° .201	10° .196	13° .192	15° .185	18° .179	20° .171	22° .162	25° .155	34° .114	42° .084	54° .043
24	0°0′ .174	2°23′ .173	4°45′ .172	7° .170	10° .166	12° .163	14° .158	16° .154	18° .148	21° .141	23° .137	32° .106	40° .079	51° .042
25	0°0′ .160	2°17′ .160	4°34′ .158	7° .157	9° .154	11° .151	14° .147	16° .143	18° .138	20° .133	22° .128	31° .101	39° .076	50° .042
30	0°0′ .111	1°54′ .111	3°50′ .111	5°43′ .109	8° .108	9° .107	11° .105	13° .103	15° .100	17° .097	18° .095	27° .080	34° .064	45° .039
36	0°0′ .077	1°36′ .077	3°11′ .077	4°46′ .076	6° .076	8° .075	9° .074	11° .073	13° .072	14° .071	16° .069	23° .061	29° .052	40° .035
40	0°0′ .063	1°26′ .062	2°52′ .062	4°17′ .062	5°43′ .062	7° .061	9° .060	10° .060	11° .059	13° .058	14° .057	21° .051	27° .045	37° .032
50	0°0′ .040	1°9′ .040	2°17′ .040	3°26′ .040	4°34′ .040	5°43′ .039	7° .039	8° .039	9° .039	10° .038	11° .038	16° .035	22° .032	31° .025
60	0°0′ .028	0°57′ .028	1°55′ .028	2°52′ .028	3°50′ .028	4°46′ .027	5°43′ .027	7° .027	8° .027	9° .027	9° .027	14° .025	18° .024	27° .020

100,000 CANDLEPOWER SOURCE

HEIGHT OF LIGHT SOURCE ABOVE SURFACE TO BE LIGHTED—FEET	0	1	2	3	4	5	6	7	8	9	10	15	20	30
100	0°0′ 10.000	0°34′ 9.999	1°9′ 9.994	1°43′ 9.987	2°17′ 9.976	2°52′ 9.963	3°26′ 9.946	4°0′ 9.927	4°34′ 9.905	5°9′ 9.880	5°43′ 9.852	9° 9.660	11° 9.439	16° 8.819
150	0°0′ 4.444	0°23′ 4.444	0°46′ 4.443	1°9′ 4.442	1°32′ 4.440	1°55′ 4.437	2°17′ 4.434	2°40′ 4.430	3°2′ 4.421	3°26′ 4.416	3°49′ 4.415	5°43′ 4.379	8° 4.324	11° 4.195
200	0°0′ 2.500	0°17′ 2.500	0°34′ 2.500	0°52′ 2.499	1°9′ 2.499	1°26′ 2.498	1°43′ 2.497	2°0′ 2.495	2°17′ 2.494	2°35′ 2.492	2°52′ 2.490	4°17′ 2.479	5°43′ 2.463	9° 2.415

* Upper figures—angle between light ray and vertical. Lower figures—footcandles on a horizontal plane produced by source.

Brightness of preheat-starting-type fluorescent lamps. The average brightness—B_a integrated across the diameter in the center of fluorescent lamps may be calculated by the formula:[27]

$$B_a = \frac{K \times F\ell}{9.25 \times D \times L}$$

where

B_a = average brightness (in cp/sq in.; 1 cp per sq in. = 452 footlamberts)
K = ratio, brightness of center section to average brightness (K = 1.09 for 20-, 30-, 40-, and 100-watt lamps)
$F\ell$ = total lumen output
D = diameter (inches)
L = luminous length (inches)

The approximate brightness B_θ of a fluorescent lamp at any angle with the lamp axis is:

$$B_\theta = \frac{\mathrm{F}\ell}{K_\theta \times D \times L \times \sin\theta}$$

where

B_θ = brightness at any angle θ (candles/sq in.)
$F\ell$ = total lumen output
K_θ = the ratio of lamp lumens to candlepower at various angles (see Table 8-16)
D = diameter (inches)
L = luminous length (inches)
θ = angle of observation

Table 8-16. Values at Various Angles of the Lamp-Lumen: Candlepower Ratio K_θ for Preheat-Starting Types of Fluorescent Lamps*

ANGLE	K_θ	Sin_θ
0°	—	0
10°	172	.174
20°	46	.342
30°	24.7	.500
40°	17.1	.643
50°	13.3	.766
60°	11.3	.866
70°	10.1	.940
80°	9.5	.985
90°	9.25	1.000

* Average for 15-, 20-, 30-, 40- and 100-watt lamps.

Calculations with surface sources.[24,23,29] An infinitely large plane source radiating light to a parallel work plane produces an illumination level:[29]

$$E = B_s$$

where B_s = source brightness (footlamberts).

with such a source (large skylight or uniformly bright ceiling in large room), the illumination is seen to be independent of the distance.

Figures 8-12, 8-13, and 8-14 provide data on several common types of luminaires.

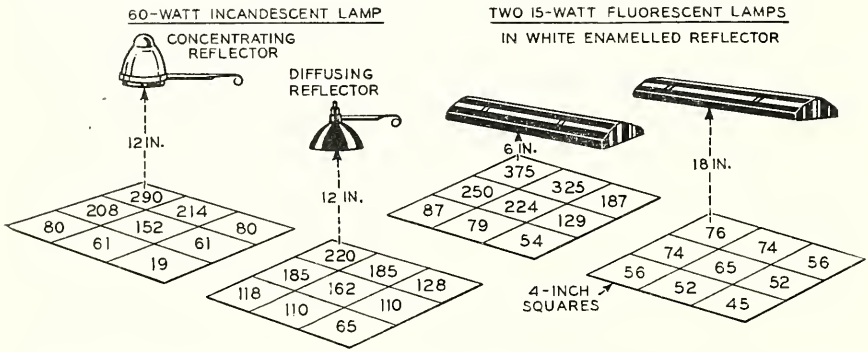


FIG. 8-12. Illumination produced by various reflector and lamp combinations at different distances from the illuminated plane. (Approximate)

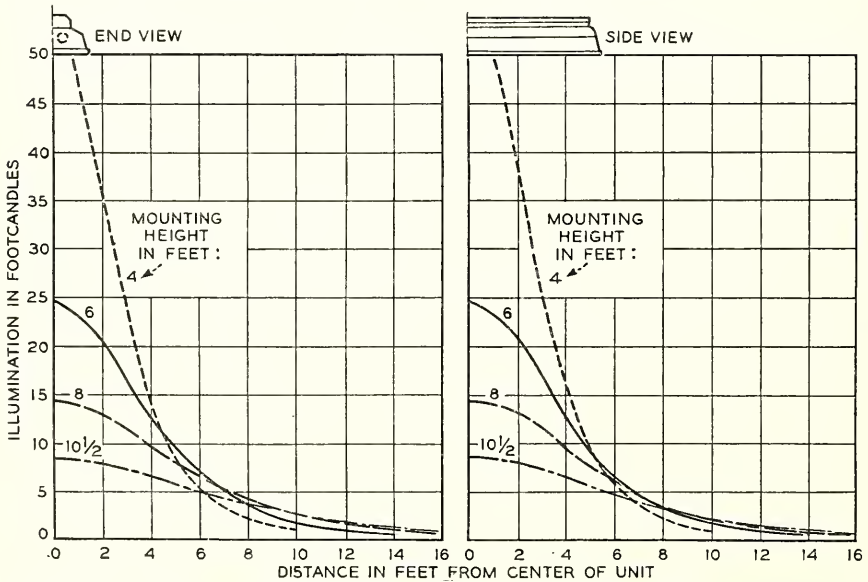


FIG. 8-13. Illumination distribution curves for a closed-end R.L.M. type fluorescent luminaire (two 40-watt white preheat-starting-type fluorescent lamps) at various mounting heights. (Based on output of 2,100 lumens per lamp)

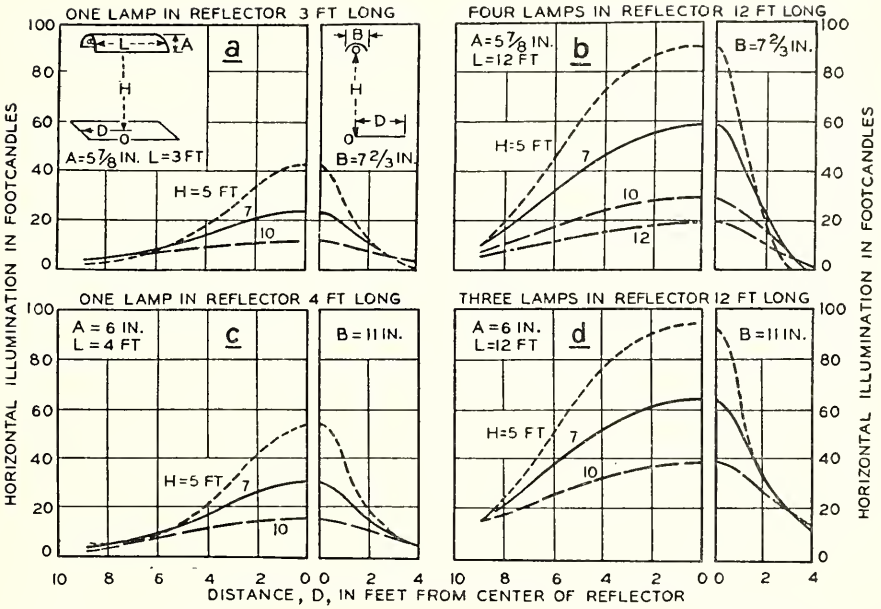


FIG. 8-14. Illumination produced by various sizes and lengths of reflectors for fluorescent lamps; a and b are for a parabolic aluminum reflector of $\frac{5}{8}$-inch focal length with a T-8 lamp producing 460 lumens per foot; c and d are for a similar reflector of $1\frac{1}{8}$-inch focal length with a T-12 lamp producing 500 lumens per foot.

For relatively small circular sources, when the distance to the point at which the illumination is to be determined is large compared to the source dimensions, the inverse square law can be applied. For closer points the illumination at points along the axis of the disk is:

$$E = \frac{F}{d^2}$$

where

F = lumen output of disk (brightness in footlamberts times area)

d = the distance from point on axis to the edge of the disk.

The formula assumes a cosine distribution and the distribution of many direct-lighting luminaires approximate this. The illumination at points along the axis can also be calculated by considering the circular source as a portion of the infinite plane, in which case:

$$E = B_s \times \sin^2\theta$$

where

E = illumination (footcandles)

B_s = source brightness (footlamberts)

θ = angle, from the point on the axis formed by axis and line to the edge of the disk.

For very close points the disk approaches an infinite plane and the formula on page 8-44 would apply. Either of these formulas may be used to determine the illumination at points along the axis of an annular or ring source by finding the illumination from the whole disk and that from the "hole" and then subtracting the latter from the former.

The curves of Fig. 8-15 and Fig. 8-16 relate the average brightness (footlamberts) of a rectangular luminous area such as a panel, window, or wall, the angles with their apexes at a given point subtended by the area, and the illumination at the point produced by the area.[14] The contribution of each such luminous area to the illumination at a given point is calculated independently. Values of illumination E at points in planes parallel or perpendicular to rectangular luminous areas may be obtained by substituting the brightness B of the area and the ratio $\left(\frac{E}{B}\right)$ from Fig. 8-15 or 8-16) in the following equation: $E = B \times \left(\frac{E}{B}\right)$

Other methods also have been developed for calculating the illumination from the sun and sky.[31]

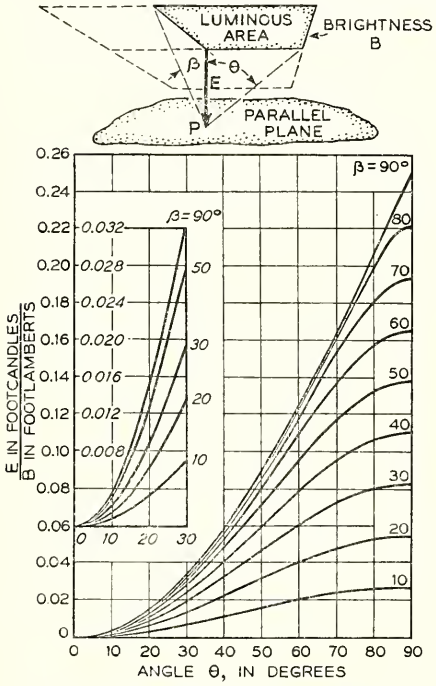


FIG. 8-15. The ratio of illumination E (at the point P of intersection of a perpendicular erected at one corner of a rectangular luminous area and a parallel illuminated plane) to the brightness B of the luminous area is a function of the angles B and θ with their apexes at the point of intersection, subtended by the rectangle sides intersecting the perpendicular.

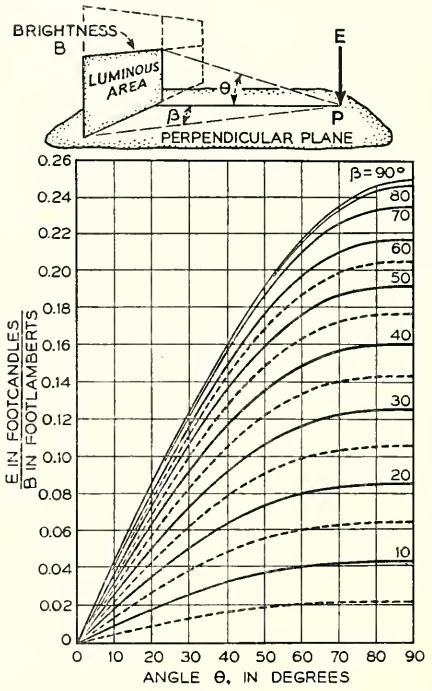


FIG. 8-16. Ratio of the illumination E (at a point P in a line perpendicular to one corner of a rectangular luminous area, which with the base of the rectangle forms the illuminated plane) to the brightness B of the luminous area is a function of the angles B and θ with their apexes at the point of intersection, subtended by the rectangle sides intersecting the perpendicular.

Street Lighting

Computations made in designing a street-lighting installation involve both point-by-point and average-flux methods of calculation.[33]

Basic photometric data. The fundamental photometric data with which spacing-mounting height relationships and utilization efficiencies of specific luminaires can be determined are given in isocandle curves. These data, together with application information, are available from manufacturers.

Isocandle curves. Figure 8-17 shows an isocandle diagram for a typical street-lighting luminaire. The curves represent the loci of points of intersection of rays of equal candlepower striking a spherical surface around the luminaire. As the curves of even an asymmetric luminaire are usually symmetrical on either side of the vertical plane at right angles to the curb line, only one hemisphere is usually necessary to show the distribution.

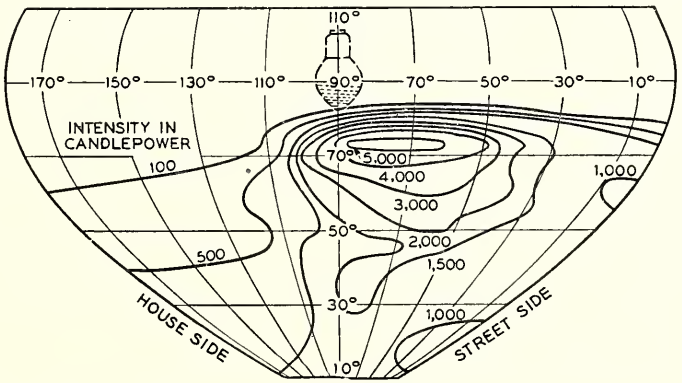


FIG. 8-17. Isocandle diagram for typical street-lighting luminaire.

Candlepower distribution curves. Most modern street-lighting luminaires produce an asymmetrical distribution of light directed in two main beams up and down the roadway. Distribution curves are customarily shown in the vertical and horizontal planes as in Fig. 8-18.

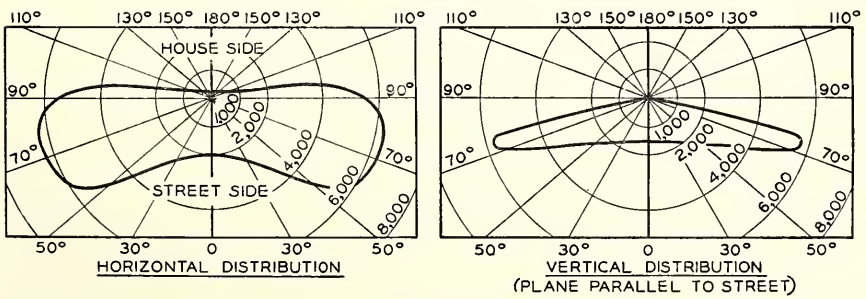


FIG. 8-18. Candlepower distribution curves for asymmetrical street-lighting luminaire.

The vertical distribution curve represents the candlepower emitted from the luminaire at various angles in a vertical plane which passes through the luminaire axis and the maximum candlepower viewed from the side. If the luminaire is asymmetrical, these will be two vertical planes. The horizontal distribution curve shows the candlepower emitted by the luminaire at specific angles in a horizontal cone through the maximum candlepower as viewed from the top.

The two curves, vertical and horizontal, through the maximum beams of the luminaire give a fairly accurate picture of the light distribution of a particular luminaire. For a more complete record an entire set of vertical and horizontal distribution curves must be obtained, with the angular interval between curves small enough to permit accurate interpolation. In practice, the isocandle curves are employed.

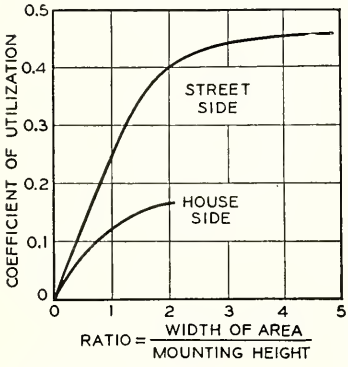


FIG. 8-19. Utilization curves for a type III street-lighting luminaire showing per cent of total lumen output falling on street and house sides of the vertical axis.

Luminaire application data. The actual performance of particular luminaires at definite spacings and mounting heights in producing illumination on the street (or the location of units to achieve specified levels) is calculated from the basic photometric data. Application information is presented in three forms: The utilization curve, general isolux curves for a single luminaire, and accumulative isolux curves for two or more luminaires under a specific set of conditions.

Utilization curves. Figure 8-19 shows utilization curves for a type III luminaire (see page 13–35). Since the luminaire directs two main beams up and down the street with a greater amount of light directed toward the street side, one curve gives the integrated portion of light which intersects areas on the house side and the other curve shows the integrated portion on the street side, expressed in per cent of the total generated light.

The formulas used are:

$$\text{Average initial illumination} = \frac{\text{Lamp lumens} \times \text{coefficient of utilization}}{\text{Spacing}^* \times \text{width of pavement}}$$

$$\text{Required lamp lumens} = \frac{\text{Area} \times \text{average initial illumination}}{\text{Coefficient of utilization}}$$

In addition to calculating average illumination, the utilization chart is also effective in determining the width of the street for which a given design is applicable.

* Spacing is measured along centerline of street. When luminaires are opposite, double the value of effective lumens.

General isolux curves. Isolux curves indicate the amount of light striking the road surface from a single unit or from a number of units. All points on a given isolux line receive the same horizontal illumination.

Isolux curves for a single luminaire can be made up for some specific mounting height with the horizontal distances shown (1) in feet, or (2) expressed as ratios of the actual distance to the mounting height, as in Fig. 8-20. To correct this type of curve for a different mounting height, the footcandle values are multiplied by the conversion factor given. This factor is the ratio of the present or stated mounting height *squared*, to the new mounting height *squared*.

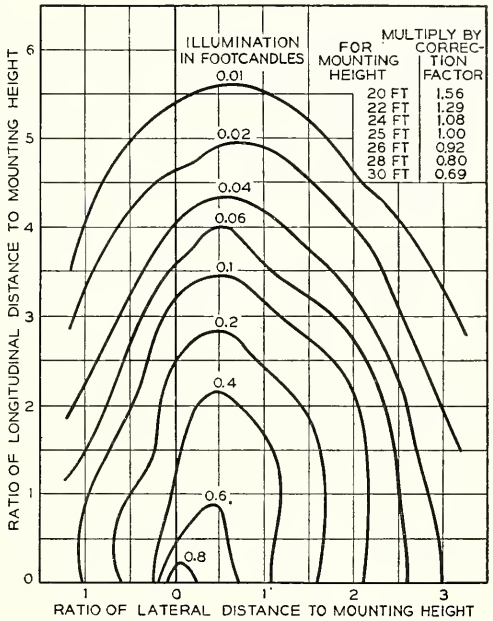


FIG. 8-20. Isolux curves for a street-lighting luminaire plotted for ratios of lateral and longitudinal distances to mounting height; the curves shown are for a 25-foot mounting height.

To determine the illumination in the horizontal plane at a given point from the second type of isolux curve (Fig. 8-20), locate the point in question and express its distance from a point directly under the luminaire in terms of the mounting height, which in this case is 25 feet. For example, the intersection of the lateral line 1 and the longitudinal line 2 is a point on the street 50 feet from the luminaire) measured along the curb line) and 25 feet from the curb toward the center of the street. The illumination at this point, from the curves, is 0.3 footcandle.

Accumulative isolux curves. When two or more luminaires are being considered as in a typical installation, the illumination is expressed by lines representing the accumulative effect of all the luminaires. Such a curve is illustrated in Fig. 8-21.

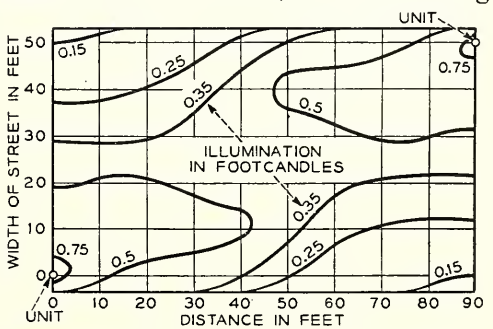


FIG. 8-21. The isolux curves shown here indicate the cumulative effect of two adjacent street-lighting luminaires.

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SECTION 9

DAYLIGHTING

As a consequence of evolution, human beings are adapted to the characteristics of daylight illumination. These characteristics vary over a wide range: At noon on a clear day with the sun directly overhead (possible only in latitudes within about 23 degrees of the equator) as high as 10,000 footcandles may be available on a horizontal plane. Clear sky alone can provide more than 1,500 footcandles and a clouded sky may produce 4,000 footcandles. Full moonlight provides about 0.02 footcandle.

Figure 9-1 shows the seasonal and daily variations in average daylight illumination characteristic of locations lying along 42 degrees north latitude (Boston, Cleveland, Chicago, Rome, or Barcelona). Locations closer to the equator usually will receive more illumination and those closer to the poles less. The number of clear and cloudy days which may be expected each year in a given area may be obtained from the United States Weather Bureau.

Duration of Sunlight on Architectural Surfaces

Neglecting local obstructions (hills, trees, buildings, clouds, etc.), the time during which sunlight will be incident on horizontal surfaces at a given latitude corresponds with the hours between sunset and sunrise for that latitude.

For sloping surfaces, the duration of sunlight incidence equals the sunrise to sunset period for a latitude equal to the local latitude plus (for north-facing slopes) or minus (for south-facing slopes) the slope angle measured down from the horizontal.

Sunlight will strike vertical surfaces during the sunrise to sunset hours in which the sun's azimuth is greater than $\theta - 90$ degrees and less than $\theta + 90$ degrees. (θ is the angle between a normal to the vertical surface and true south.)

Window Design

Through well-designed and regularly cleaned skylights, windows, doors, and glass-block wall areas, useful quantities of daylight may be provided in buildings. For most purposes, the higher the daylight illumination level in a building the better, providing the illumination is uniformly distributed and the brightness ratios are within comfortable limits.

It is recommended that windowed buildings be designed so that a daylight illumination level of at least 10 footcandles will be provided over the entire horizontal working plane. In the northern hemisphere a sky brightness representative of conditions encountered at eight o'clock in the morning on a December twenty-first with cloudy sky is a common basis for design.

Note: References are listed at the end of each section.

The *international standard of sky brightness* (5,000 lux, or 465 footlamberts) is of the same order of magnitude as that of cloudy December morning skies likely to be observed in the northern United States.

Using this value and Figs. 8-15 and 8-16, the minimum daylight illumination likely to be provided at any point on a horizontal plane by rectangular window or skylight openings may be determined.

Design factors. Because windows absorb some light when clean and more when dirty, the values obtained from Figs. 8-15 and 8-16 should be multiplied by an efficiency and a maintenance factor.

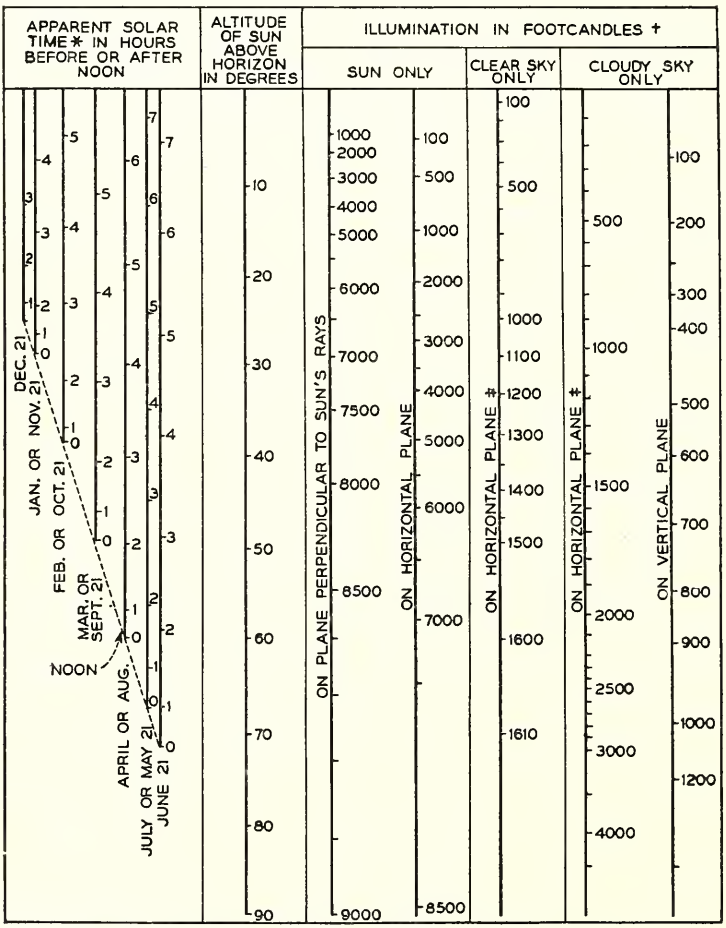


FIG. 9-1. Average daylight illumination at various times and in various planes at 42 degrees north latitude.[1]

Glass and efficiency. Three types of window glass are in common use:

TYPE	CLEAN TRANSMITTANCE
Clear sheet	82–90% (depending on color)
Ribbed	67–84% (depending on color and pattern)
Rough or hammered	50–88% (depending on color and pattern)

For the average office window with clear water-white glass, a single transom, and few mullions, 80 per cent is a representative efficiency. A factor of 60 per cent should be used for the average factory window with many small panes.

Maintenance factors. Maintenance factors will vary over a wide range depending on the local atmosphere, the cleaning schedule, the glass surface and the window slope. Values for factory windows cleaned twice each year are given in Fig. 9-2.

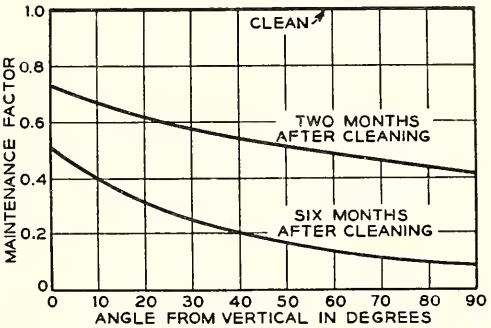


FIG. 9-2. The effect of slope on the dirt collection rate of a typical factory window is revealed by this plot of the maintenance factor (glass transmittance six months after cleaning) as a function of slope.[2]

Window Design Evaluation and Comparison

Tables 9-1, 9-2, and 9-3* and Figs. 9-3 to 9-6, inclusive, which were developed from test data on factory-type windows, facilitate comparisons between different designs.[2] The values given are based on a sky brightness of approximately 980 footlamberts and a series of windows 100 feet long. The possible contribution of interreflections is not included.

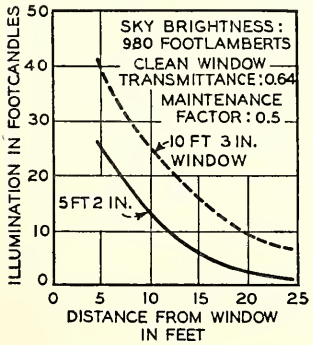


FIG. 9-3. Effect of window height on daylight illumination on a horizontal plane at sill height in a building with a 100-foot-long series of windows in one wall (neglecting interreflections).[2]

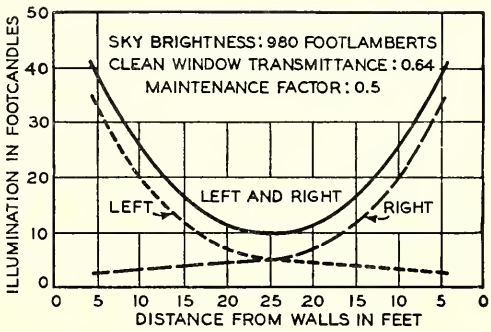


FIG. 9-4. Daylight illumination at various points on a horizontal plane at sill height in a 50-foot-wide rectangular building with a 100-foot-long series of windows (8 feet 6¾ inches high) in each of two opposing walls (neglecting interreflections).[2]

* Pages 9-7, 9-8, and 9-9

The measured values have been multiplied by an efficiency factor of 64 per cent (80 per cent glass transmittance times 80 per cent absorptance for transoms, muntins, and mullions) and by a maintenance factor (50 per cent for vertical windows or 25 per cent for windows with a 30-degree slope).

Figure 9-7* gives factors by which the tabulated and plotted values may be multiplied in order to obtain values for other than 100-foot window lengths. To determine illumination for values of sky brightness other than 980 footlamberts, the data should be divided by 980 and multiplied by the new brightness.

The following rules of thumb direct attention to several variables which should be considered when different designs are being evaluated

1. The window area should be as large as practicable and at least equal to 25 per cent of the floor area. When near-by trees or buildings reduce the sky area visible from the windows, the ratio of window to floor area should be increased above 25 per cent.
2. Windows should be placed as high in a wall as practicable and in more than one wall whenever possible.
3. Transoms, muntins, and mullions should be made as small in cross section as possible and a minimum number should be used.
4. Deep reveals should be splayed.
5. For a given window area, small in comparison to that of a wall, greater uniformity of illumination will result from two small windows spaced not farther apart than their combined width than from a single centered window.
6. Some type of brightness control should be planned for windows which will receive direct sunlight.

Brightness Control

In offices, roller shades or Venetian blinds are used to reduce the apparent source brightness. In factories, saw-tooth roofs usually face north and are sloped so that no direct sunlight is admitted. A saw-tooth roof can be constructed with windows facing south; however, with this orientation some means for diffusing the direct sunlight should be used in summer. Diffusers reduce the maximum illumination to a greater extent than they do the minimum and therefore improve uniformity.

A coat of whitewash or other diffuse transmittance material sometimes is sprayed on a glass window late in the spring and washed off in the fall. It should be noted that ordinary whitewash (slaked lime) may etch a glass surface slightly during the summer and consequently hasten the accumulation of dirt the following winter.

Heat-absorbing glass with permanent diffusing surfaces has lower transmittance than ordinary glass, but when it is used the application and removal of the diffuser are unnecessary.

Painting. Finishing an interior with high-reflectance paint or other coating increases the daylight as well as the electrical illumination level

* Page 9-7.

over that which might be expected with low-reflectance surfaces. The amount of increase depends upon window area, room dimensions, wall and ceiling reflectances, and ground brightness. To coat the exterior of the saw-tooth roof and vertical walls of courts or of adjacent buildings with a high-reflectance material will increase the daylight illumination also.

Roof Windows

A building can be too wide to obtain adequate daylight illumination through side-wall windows alone. Roof windows may be used to increase the daylight illumination in the center of the structure. Roof windows are of three general types: (1) vertical or sloping in monitors; (2) vertical or sloping in saw teeth; (3) skylights.

Figure 9-5 represents a building 100 feet wide with windows in the side walls 12 feet high. On the roof of this building are shown: (1) a monitor with 6-foot vertical windows; (2) a monitor with 6-foot windows on a 30-degree slope; (3) 6-foot skylights on a 60-degree slope.

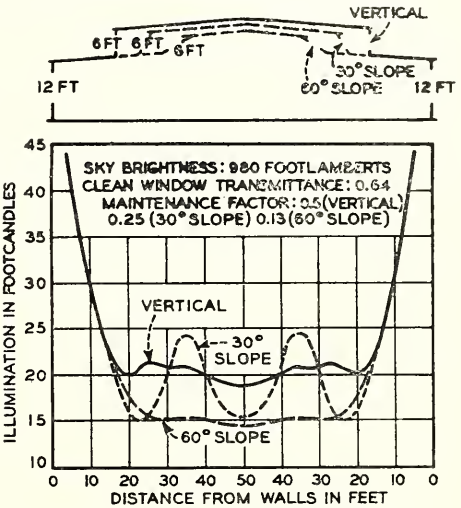


FIG. 9-5. Effect of monitor design on daylight illumination at various points on a horizontal plane at sill height, in a 100-foot-wide rectangular building with a 100-foot-long series of windows (12 feet high) in each of two opposing walls (neglecting interreflections).[3]

Notice that the glass area is the same in all three, and that each glass area is so located as to provide the best daylight illumination of which it is capable. The curves show the footcandles transmitted to the horizontal reference plane by each of these three roof designs added to those transmitted by the side-wall windows.

Monitor design. As a general rule, the best daylighting can be secured through vertical windows in a monitor half as wide as the building. A monitor should be no higher than half its width, and should be at least twice as wide as its window height. When the width of a monitor is less than twice the height of its windows, light transmitted by the upper panes will be cut off by the roof line.

Increasing the height of a monitor, whether it be wide or narrow, increases the minimum illumination faster than it does the maximum and thus helps to secure uniformity. Occasionally, sloping glass in a wide monitor results in a greater proportionate increase in the minimum illumination level in a building than in the maximum. Whether the windows are vertical or sloping, an increase in their glass area always results in an increase in the minimum illumination.

Saw-tooth roofs. Saw-tooth roofs often are provided in a building so wide that light from side-wall windows is ineffective over a large area in the center of the building. Frequently they are used to provide a uniform level of north-sky light.

Usually the faces of the teeth (the sides containing windows) are turned to the north to secure the advantages of daylight with a minimum discomfort from direct sunlight. In some instances it may be advantageous to face the saw teeth to the south. The southern sky usually is brighter than the northern sky and thus ensures maximum daylight illumination in the dark winter months. For southern orientations, probably it will be necessary to provide some means of brightness control for summer use.

The design and location of saw teeth should follow the principles outlined for monitors. Usually the open width (base of triangle) should not be less than twice the height of saw-tooth windows.

Thirty-degree sloping windows six months after cleaning will admit no more light than vertical windows six months after cleaning. Either is likely to provide more than 10 footcandles on the horizontal reference plane if the glass area is more than 30 per cent of the floor area. Narrowing the span of the saw teeth or increasing the height of the windows increases the minimum daylight illumination faster than it increases the maximum. This is illustrated in the diagrams of Fig. 9-6. The illumination curve for a 40-foot saw tooth is shown at the left. At the right is shown what happens when the 40-foot saw tooth is converted into two 20-foot was teeth, the window height remaining unchanged. Note how the minimum illumination increases while the maximum illumination remains about the same, thus improving the uniformity.

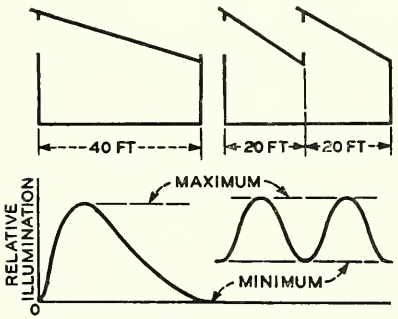


FIG. 9-6. Effect of saw-tooth roof design on relative daylight illumination distribution inside a building (neglecting interreflections).

Multistory Buildings

Multistory buildings frequently are erected in congested districts. They often are built in the form of an **E** or a **U**. The chief multistory daylighting problem is the interference caused by surrounding buildings or by other parts of the same building.

When the windows in a multistory building are of uniform height and any structure is located near enough to shade them, the illumination on any given floor of the building will be considerably lower than it is on the floor above.

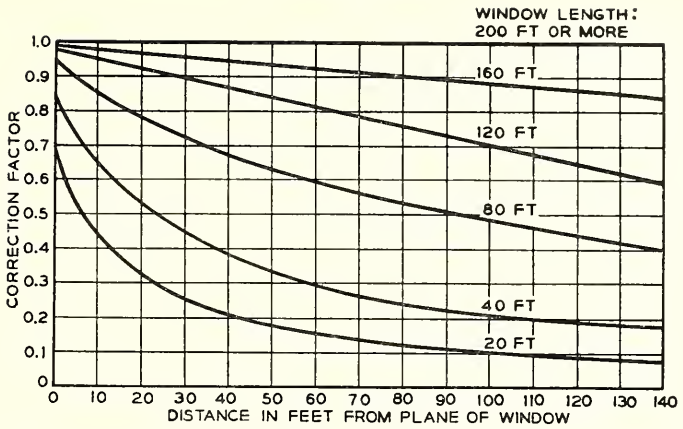


FIG. 9-7. To determine the daylight illumination at any distance from a window series of a length other than 100 feet, multiply the value for a 100-foot-long series (found in Figs 9-3, 9-4, & 9-5), by the appropriate factor selected from these curves.[2]

Table 9-1. Daylight Illumination (in Footcandles) Provided at Various Points on a Horizontal Plane at Sill Height by a 100-Foot-Long Series of Sidewall Windows of Various Heights*

FEET BACK FROM WINDOW	WINDOW HEIGHT												
	5′2″	6′10″	8′6″	10′3″	11′11″	13′7″	15′4″	17′0″	18′9″	20′5″	22′2″	23′11″	25′7″
5	25	30	35	39	42	44	47	48	50	52	53	54	55
10	13	16	20	24	28	32	35	38	40	42	44	45	47
15	7.5	9.8	12	16	19	22	24	27	30	33	34	36	38
20	4.8	6.2	8	10	13	16	18	21	23	26	28	30	32
25	3.3	4.3	5.5	7.3	9.6	12	14	16	18	21	22	24	26
30	2.4	3.2	4.1	5.5	7.3	8.8	11	12	14	17	18	20	21
35	1.8	2.4	3.2	4.2	5.5	6.8	8.1	10	12	13	15	16	18
40	1.4	1.8	2.4	3.3	4.4	5.5	6.5	7.8	9.2	11	12	13	15
45	1.1	1.5	2.0	2.6	3.5	4.3	5.2	6.4	7.4	8.6	9.6	11	12
50	0.9	1.2	1.6	2.1	2.8	3.4	4.2	5.0	6.0	7.0	8.0	9	10
55	0.7	1.0	1.3	1.8	2.3	2.8	3.5	4.2	4.9	5.8	6.6	7.5	8.5
60	0.6	0.8	1.1	1.4	1.9	2.3	2.9	3.4	4.1	4.8	5.6	6.4	7.2
65	0.5	0.7	0.9	1.2	1.6	2.0	2.4	2.9	3.4	4.0	4.6	5.3	6.1
70	0.4	0.6	0.8	1.0	1.4	1.7	2.1	2.5	3.0	3.5	4.0	4.6	5.1
75	0.4	0.5	0.7	0.9	1.2	1.5	1.8	2.2	2.5	3.0	3.5	4.0	4.6
80	0.3	0.4	0.6	0.8	1.0	1.3	1.6	1.9	2.2	2.6	3.1	3.5	4.0
85	0.3	0.4	0.5	0.7	0.9	1.1	1.4	1.7	2.0	2.3	2.6	3.1	3.5
90	0.2	0.3	0.5	0.6	0.8	1.0	1.2	1.5	1.8	2.1	2.4	2.8	3.1
95	0.2	0.3	0.4	0.5	0.7	0.9	1.1	1.3	1.5	1.8	2.1	2.5	2.8
100	0.2	0.3	0.4	0.5	0.7	0.8	1.0	1.2	1.4	1.7	1.9	2.2	2.5
105	0.2	0.3	0.3	0.4	0.6	0.7	0.9	1.1	1.3	1.5	1.8	2.0	2.3
110	0.2	0.2	0.3	0.4	0.6	0.7	0.8	1.0	1.1	1.4	1.6	1.9	2.1
115	0.2	0.2	0.3	0.4	0.5	0.6	0.7	0.8	1.0	1.3	1.5	1.7	1.9
120	0.1	0.2	0.3	0.4	0.5	0.5	0.7	0.8	0.9	1.2	1.3	1.6	1.7
125	0.1	0.2	0.2	0.3	0.5	0.5	0.7	0.7	0.9	1.1	1.2	1.4	1.6
130	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.7	0.8	1.0	1.1	1.3	1.5
135	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.7	0.8	1.0	1.0	1.2	1.3
140	0.1	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2

* Sky brightness, 980 footlamberts; efficiency factor, 0.64; maintenance factor, 0.50; interreflections neglected.[2] Correction factors for other lengths given in Fig. 9-7.

The daylighting on every floor of a multistory building can be improved by widening the distance between it and the shading structure. The daylighting on the lower floors will be improved more than that on the upper floors. Closing the open space of an **E**- or a **U**-shaped building to form a court reduces the illumination within the building; the greatest reduction occurs on the lower floors.

Service towers on the near walls of adjacent buildings tend to reduce the minimum illumination on lower floors of the opposite buildings as much as one third to one half.

Table 9-2. Daylight Illumination (in Footcandles) Provided at Various Points on a Horizontal Plane by a 100-Foot-Long Series of Sidewall Windows of Various Heights with Sills at Various Heights Above the Plane*

FEET BACK FROM WINDOW	SILL HEIGHT ABOVE HORIZONTAL REFERENCE PLANE																				
	15 feet					25 feet					35 feet					45 feet					
	Window height					Window height					Window height					Window height					
	3'6"	5'2"	6'10"	8'6"	10'3"	3'6"	5'2"	6'10"	8'6"	10'3"	3'6"	5'2"	6'10	8'6"	10'3"	3'6"	5'2"	6'10"	8'6"	10'3"	
5	3.0	4.0	5.1	6.0	6.7	1.2	1.5	1.8	2.1	2.5	0.6	0.9	1.1	1.4	1.6	0.4	0.9	1.4	2.0	2.9	
10	5.8	7.4	9.8	11.2	12.0	2.2	3.0	3.6	4.3	4.7	1.3	1.9	2.3	2.9	3.6	1.2	1.7	2.4	3.3	4.2	
15	6.6	8.0	10.6	12.8	13.8	3.0	4.4	5.2	6.5	7.1	1.9	2.7	3.3	4.3	5.2	1.7	2.5	3.3	4.1	5.1	
20	6.0	7.7	9.8	12.1	13.6	3.5	5.1	6.3	7.8	9.0	2.4	3.3	4.0	5.4	6.6	2.3	3.2	4.0	4.8	5.8	
25	5.1	6.8	8.5	10.6	12.1	3.8	5.2	6.6	8.3	9.8	2.7	3.6	4.5	5.9	7.3	2.7	3.8	4.6	5.4	6.3	
30	4.3	5.8	7.5	9.2	10.7	3.6	5.0	6.1	8.4	10.0	2.9	3.7	4.6	6.0	7.5	2.9	4.2	4.9	5.8	6.6	
35	3.6	4.8	6.4	7.8	9.1	3.4	4.6	6.2	7.8	9.2	2.7	3.6	4.5	5.9	7.5	2.8	4.0	4.9	5.7	6.4	
40	3.1	4.0	5.4	6.6	7.8	3.1	4.2	5.5	7.0	8.1	2.5	3.4	4.3	5.8	7.1	2.6	3.7	4.6	5.5	6.2	
45	2.5	3.4	4.5	5.5	6.6	2.8	3.7	4.9	6.2	7.3	2.3	3.1	4.0	5.3	6.8	2.4	3.5	4.4	5.2	5.9	
50	2.1	2.8	3.7	4.7	5.6	2.6	3.3	4.4	5.5	6.5	2.1	2.8	3.7	4.9	6.4	2.2	3.2	4.0	4.9	5.5	
55	1.7	2.4	3.0	3.9	4.8	2.3	2.9	3.9	4.9	5.8	1.9	2.6	3.3	4.5	5.9	2.0	2.9	3.7	4.5	5.3	
60	1.3	2.0	2.5	3.3	4.0	2.0	2.6	3.4	4.4	5.2	1.7	2.3	3.0	4.1	5.4	1.9	2.6	3.5	4.2	4.9	
65	1.1	1.7	2.1	2.8	3.4	1.8	2.3	3.1	3.9	4.6	1.6	2.1	2.7	3.7	4.8	1.7	2.4	3.2	3.9	4.6	
70	0.9	1.4	1.8	2.4	3.0	1.5	2.1	2.7	3.4	4.0	1.4	1.9	2.4	3.4	4.3	1.5	2.2	2.9	3.6	4.3	
75	0.8	1.2	1.5	2.1	2.5	1.4	1.9	2.4	3.0	3.5	1.3	1.8	2.2	3.0	3.9	1.4	2.0	2.7	3.4	4.1	
80	0.6	1.0	1.3	1.8	2.2	1.3	1.6	2.2	2.7	3.1	1.2	1.6	2.0	2.7	3.5	1.2	1.8	2.4	3.1	3.8	
85	0.5	0.9	1.2	1.6	2.0	1.1	1.5	1.9	2.4	2.8	1.1	1.4	1.8	2.4	3.1	1.1	1.7	2.2	2.9	3.6	
90	0.5	0.8	1.0	1.4	1.8	0.9	1.3	1.7	2.1	2.5	1.0	1.3	1.7	2.2	2.8	1.0	1.5	2.1	2.7	3.3	
95	0.4	0.6	0.9	1.2	1.6	0.8	1.1	1.5	1.8	2.2	0.9	1.2	1.5	2.0	2.5	1.0	1.4	2.0	2.5	3.1	
100	0.4	0.6	0.8	1.1	1.4	0.7	0.9	1.2	1.5	2.0	0.9	1.1	1.4	1.8	2.3	0.9	1.3	1.9	2.3	2.9	
105	0.4	0.5	0.7	0.9	1.3	0.5	0.8	1.0	1.4	1.8	0.8	1.1	1.3	1.7	2.1	0.8	1.2	1.7	2.2	2.7	
110	0.3	0.5	0.6	0.8	1.1	0.4	0.6	0.9	1.2	1.2	0.8	1.0	1.2	1.6	2.0	0.8	1.1	1.6	2.1	3.0	
115	0.3	0.4	0.5	0.7	1.0	0.4	0.5	0.7	1.0	1.4	0.7	1.0	1.2	1.5	1.9	0.7	1.0	1.5	2.0	2.3	
120	0.3	0.4	0.5	0.6	0.8	0.3	0.5	0.6	0.9	1.2	0.7	0.9	1.1	1.4	1.7	0.7	1.0	1.4	1.8	2.2	
125	0.2	0.3	0.4	0.6	0.8	0.3	0.4	0.6	0.8	1.1	0.7	0.9	1.1	1.3	1.6	0.6	0.9	1.3	1.7	2.1	
130	0.2	0.3	0.4	0.5	0.7	0.2	0.4	0.5	0.7	1.0	0.6	0.9	1.1	1.3	1.5	0.6	0.9	1.2	1.6	1.9	
135	0.2	0.3	0.4	0.5	0.6	0.2	0.3	0.4	0.6	0.9	0.6	0.8	1.0	1 2	1.4	0.6	0.8	1.1	1.5	1.9	
140	0.2	0.3	0.3	0.4	0.6	0.2	0.3	0.4	0.5	0.8	0.6	0.8	1.0	1.2	1.4	0.6	0.8	1.1	1.5	1.8	

* Sky brightness, 980 footlamberts; efficiency factor, 0.64; maintenance factor, 0.50; interreflections neglected.[2] Correction factors for other lengths given in Fig. 9-7.

Where uniformity throughout a building is important, approximately equal minimum daylight can be obtained on all floors by increasing (below the top floor) the window heights and window-to-floor area ratios. The greatest increase is necessary on the ground floor. The top-story window area should equal about 30 per cent of the floor area.

The use of high-reflectance brick, tile, or paint for the walls of enclosed courts in place of low-reflectance surfaces may produce a large increase in daylight illumination on the lower floors.

Table 9-3. Daylight Illumination (in Footcandles) Provided at Various Points on a Horizontal Plane by a 100-Foot-Long Series of 30-Degree Sloping Windows of Various Heights with Sills at Various Heights above the Plane*

FEET FROM PLANE OF WINDOW†	SLANT HEIGHT OF SILL‡															
	15 Feet				25 Feet				35 Feet				45 Feet			
	Slant Height of Window				Slant Height of Window				Slant Height of Window				Slant Height of Window			
	3′0″	6′0″	9′0″	12′0″	3′0″	6′0″	9′0″	12′0″	3′0″	6′0″	9′0″	12′0″	3′0″	6′0″	9′0′	12′0″
5	1.6	2.6	3.3	3.9	0.6	1.0	1.5	2.1	0.5	0.8	1.1	1.5	0.2	0.4	0.6	0.8
10	4.8	8.3	10.6	16.9	1.6	2.3	3.5	4.6	0.9	1.5	2.2	2.9	0.5	0.8	1.3	1.8
15	7.0	13.8	18.4	21.3	2.5	4.1	6.3	7.4	1.3	2.3	3.4	4.5	0.8	1.6	2.3	2.9
20	4.9	10.1	16.3	19.3	3.3	6.2	8.9	10.1	1.7	3.1	4.6	6.0	1.2	2.4	3.3	4.3
25	3.5	6.8	11.9	16.2	3.9	7.1	9.6	11.6	2.0	3.8	5.7	7.5	1.6	3.1	4.5	5.8
30	2.5	4.9	8.5	12.8	3.5	6.8	9.5	11.9	2.4	4.6	6.7	8.9	1.5	3.9	5.8	7.4
35	1.8	3.8	6.3	9.8	3.0	6.1	8.9	11.7	2.8	5.3	7.6	10.0	2.3	4.5	6.8	8.6
40	1.3	3.0	5.1	7.8	2.6	5.4	8.1	11.1	2.9	5.6	8.1	10.6	2.5	4.7	7.1	9.1
45	1.0	2.4	4.3	6.2	2.2	4.7	7.2	9.8	2.7	5.2	7.6	10.0	2.4	4.7	7.0	9.1
50	0.8	1.9	3.6	5.3	1.9	4.0	6.3	8.6	2.3	4.6	6.9	9.1	2.3	4.5	6.9	8.9
55	0.6	1.6	3.0	4.4	1.7	3.5	5.3	7.5	2.0	4.1	6.2	8.3	2.1	4.2	6.5	8.6
60	0.5	1.4	2.5	3.8	1.4	3.0	4.5	6.4	1.7	3.6	5.5	7.5	1.9	3.9	6.0	8.0
65	0.5	1.2	2.1	3.2	1.2	2.5	3.8	5.5	1.5	3.1	4.9	6.8	1.8	3.5	5.5	7.3
70	0.4	1.0	1.7	2.7	1.0	2.1	3.2	4.7	1.3	2.6	4.3	6.1	1.6	3.2	5.0	6.7
75	0.4	0.8	1.5	2.3	0.9	1.7	2.7	4.0	1.1	2.3	3.8	5.4	1.4	2.9	4.5	6.1
80	0.3	0.7	1.2	1.9	0.7	1.4	2.2	3.3	0.9	2.0	3.2	4.8	1.3	2.6	4.0	5.5
85	0.3	0.6	1.0	1.6	0.6	1.2	1.9	2.7	0.8	1.7	2.8	4.1	1.1	2.3	3.5	5.0
90	0.3	0.5	0.9	1.4	0.5	1.0	1.6	2.3	0.7	1.5	2.4	3.5	1.0	2.0	3.1	4.4
95	0.3	0.4	0.7	1.1	0.4	0.9	1.3	1.9	0.6	1.3	2.1	3.0	0.9	1.8	2.8	3.9
100	0.2	0.4	0.6	1.0	0.4	0.7	1.2	1.6	0.5	1.1	1.9	2.6	0.8	1.6	2.5	3.5
105	0.2	0.3	0.5	0.8	0.3	0.6	1.0	1.5	0.5	1.0	1.6	2.3	0.7	1.4	2.3	3.2
110	0.2	0.3	0.5	0.7	0.3	0.6	0.9	1.3	0.4	0.9	1.4	2.0	0.6	1.3	2.1	2.9
115	0.2	0.3	0.4	0.6	0.3	0.5	0.8	1.1	0.4	0.8	1.3	1.8	0.6	1.2	1.9	2.6
120	0.2	0.3	0.4	0.5	0.2	0.5	0.7	1.0	0.4	0.7	1.1	1.6	0.5	1.1	1.8	2.4
125	0.2	0.2	0.4	0.5	0.2	0.4	0.6	0.9	0.3	0.7	1.0	1.4	0.5	1.0	1.6	2.2
130	0.2	0.2	0.3	0.4	0.2	0.4	0.6	0.8	0.3	0.6	0.9	1.3	0.4	0.9	1.4	2.0
135	0.2	0.2	0.3	0.4	0.2	0.4	0.5	0.8	0.2	0.6	0.9	1.2	0.4	0.9	1.3	1.8
140	0.1	0.2	0.3	0.4	0.2	0.4	0.5	0.7	0.2	0.5	0.8	1.1	0.3	0.8	1.2	1.6

* Sky brightness, 980 footlamberts; efficiency factor, 0.64; maintenance factor, 0.50; interreflections neglected.[2] Correction factors for other lengths given in Fig. 9-7.
† Measured from intersection of window plane and horizontal reference plane.
‡ Measured between sill and intersection of window plane and horizontal reference plane.

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SECTION 10

INTERIOR LIGHTING

The problems encountered in applying light to building interiors have so many ramifications that the popular use of the term "illuminating engineering" often is restricted to such applications. This usage suggests the importance of this field as compared with most other phases of the lighting art and science.

Usually, there are many correct solutions to a lighting problem. Modern standards call for the provision of both quantity and quality which are commensurate with the severity of the seeing tasks encountered by the occupants of a given area and which minimize the fatigue resulting from visual effort. Lighting should enhance the over-all appearance of an interior.

To achieve these goals, bearing in mind that humans are mobile that their physical as well as mental ability to see varies as do their tastes, is a major objective of the illuminating engineering profession.

The solution of an interior lighting problem involves the following considerations:

Architecture. The physical structure in which light is to be applied determines to a large degree the form and disposition of the lighting facilities. It is reasonable to construct a building so that daylight may be used whenever available. Daylight, however, varies with the geographical as well as the immediate location, and with the time of day, the season of the year, the weather and the presence of adjacent objects such as trees and buildings. Daylight is "free" but its transfer to the place of work at the time desired may be costly or impractical. Most buildings need an electrical-lighting system also.

Though many of the graphs, formulas, and tables of this and other sections of the handbook are basic in lighting technology, lighting art is not subject to the same degree of standardization, since it is influenced in all its aspects by individual interpretation.

Architecture comprises the aesthetic as well as the physical and economic aspects of structures. This is equally true of lighting; the two are not separable. Many buildings such as theaters emphasize aesthetic considerations to such a degree that these appear paramount to the casual observer. Lighting is used by the architect in dramatizing the other features of his plan. Aesthetic considerations are not always of such great importance, but they should never be ignored.

Function of a building. The function of a building or other structure greatly influences the way in which lighting is applied. A person when reading encounters the same type of visual task regardless of his location whether it be in a factory, in an office, or in a home, but such factors as economics, appearance, continuity of effort, and quality of results desired influence the lighting design developed for the reading area. Thus application techniques generally designated as industrial lighting, store

NOTE: References are listed at the end of each section.

lighting, office lighting, and so on have developed. Each of these is a synthesis of engineering theory, application experience, and consumer acceptance and desire in a particular field. Because these include more than an objective assessment of engineering considerations, it is necessary to relate the design of a lighting installation to the particular occupancy of the space it is to serve.

Lighting method. For most purposes it usually is impractical or impossible and undesirable to duplicate exactly natural lighting indoors either in illumination level, in spectral quality, or in distribution. Layouts of luminaires may be described as general, local, localized general, or supplementary. Five standard luminaire classifications, based on distribution characteristics, have been defined: direct, semidirect, general diffuse, semi-indirect, and indirect. The lighting facilities may be an integral part of the physical structure or, as is more often the case at present, may be attached to it.

Light source. The choice of light source, of luminaire characteristics, and of the system layout are closely interrelated in an application technique. A method easily applied with one type of source may be equally applicable or most impractical with another. Frequently local conditions of vibration, ambient temperature, or dust and dirt influence light source operation, output, and maintenance and, indirectly therefore, the application technique. (See also Section 6.)

Economics. Both initial and operating costs affect the design of a lighting system. There is no sharp line of demarcation between excellent and good lighting, between good and average, between average and poor. There is no easy way to predict the exact value of commercial or industrial lighting in terms of production, safety, quality control, employee morale, or employee health; or to weigh the importance of home lighting in dollars and cents Nevertheless, illuminating engineers must balance costs against the attainable results in developing any lighting design, relying to a great extent, at present, upon experience gained in the solution of comparable problems if such is available.

LIGHTING METHODS

Today the elementary approach to the solution of lighting problems assumes small rooms (under 500 square feet) or bays (floor spaces resulting from the subdivision of a larger area by columns or other architectural supporting members), with ceiling heights between 8 and 14 feet. It assumes also that the illumination will be supplied from luminous areas small in proportion to the floor area they illuminate, suspended from the ceiling or surface mounted on ceiling or side walls.

This approach is changing slowly. The trend toward large area sources that began prior to the availability of the fluorescent lamp was given increased momentum by its development Many large structures have clear floor spaces far in excess of 500 square feet. Nevertheless, the common approach follows a definite pattern.

Luminaire Layout

The illuminating engineer has classified several types of lighting installations according to luminaire layout as follows:

General lighting is the name given to an arrangement of artificial sources, usually symmetrical in plan, which attempts to distribute light flux throughout a room to provide approximately uniform illumination on the working plane. Unless otherwise required or specified, the working plane is considered to be 30 inches above the floor. The greatest advantages of general lighting are its independence of seeing task location and the relative simplicity of its installation and adjustment. The light distribution is similar to that provided out-of-doors. (See Fig. 10-1.)

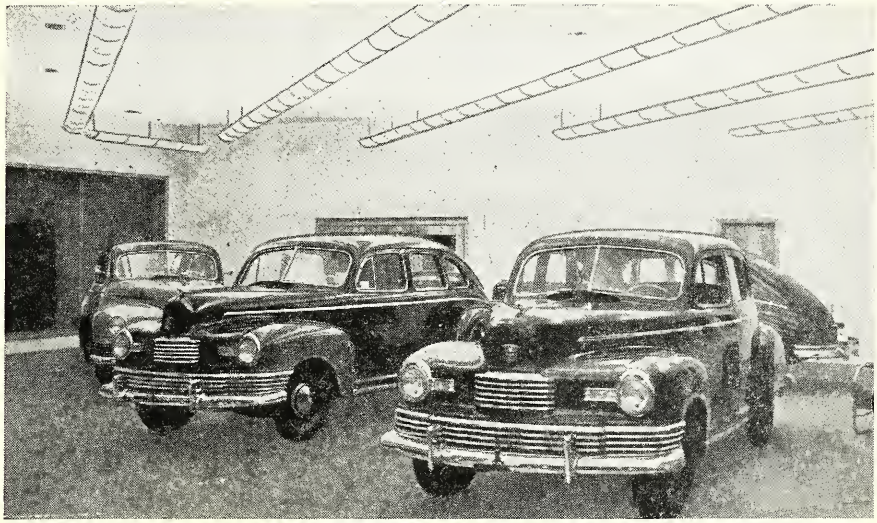


FIG. 10-1. General lighting.

Localized general lighting utilizes luminaires mounted above the visual task which contribute also to the illumination of the surround. This compromise method utilizes the best points of general and local lighting and, at the same time, minimizes their limitations. Like any compromise, its success depends very much on whether the limitations of the fundamental methods are important in the installation in question. (See Fig. 10-2.)

Local lighting is the term applied to an installation of luminaires mounted at or near the location where illumination is required for a specific seeing task. Occasionally, as in certain types of spotlighting, the result is local, although the equipment may be remotely placed. The greatest advantages of local lighting lie in its relatively low cost for high-illumination levels on the task, and in its adjustment flexibility in the area of the seeing task. When used with general lighting it is called *supplementary*. (See Fig. 10-3.)

Supplementary lighting may be provided by a variety of luminaire types used in conjunction with general lighting. The luminaires are installed

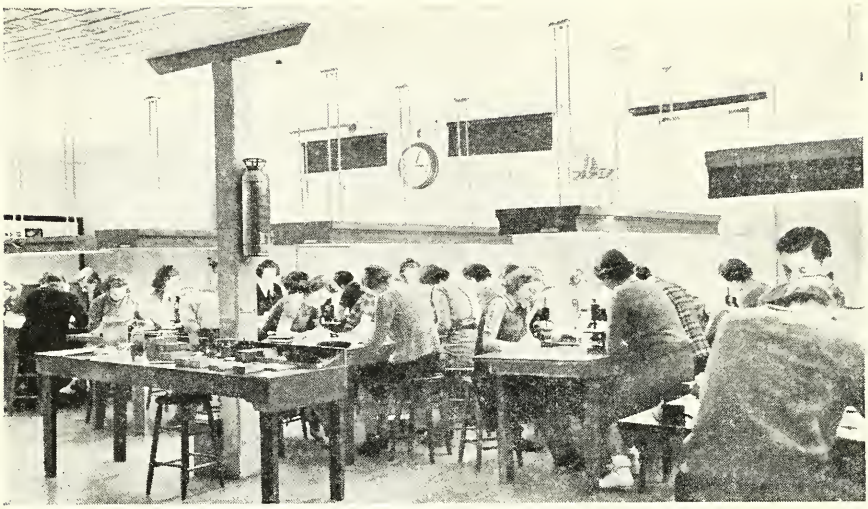


FIG. 10-2. Localized general lighting.



FIG. 10-3. Local lighting.

so as to increase the illumination level on a seeing task and its immediate surround when it is not necessary or practicable to provide the same level over the wider areas covered by local, localized-general, or general-lighting installations. (See Fig. 10–4.)

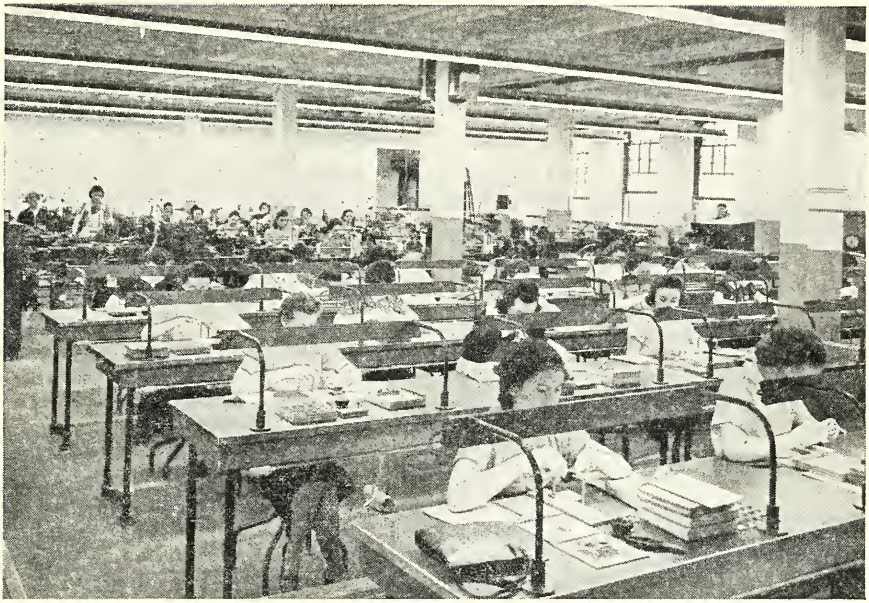


FIG. 10-4. Supplementary lighting.

Luminaire Classifications

The manner in which light from a lamp is controlled by a luminaire affects brightness patterns, glare, and shadows through distribution and diffusion. Luminaires are classified by the International Commission on Illumination (I. C. I.) in accordance with the way in which they control the light as in Table 10–1.

Wherever light is applied the directional component is important from architectural considerations. The play of light and shadow often establishes the character of the structure; areas of contrasting brightness may indicate spaciousness, height, isolation, coziness, and so on. Thus the basic ways of directing light, even though they have evolved because of practical application considerations and are most often considered as a luminaire problem, should be viewed from an architectural standpoint as well.

Table 10-1. I.C.I. Luminaire Distribution Classifications

(See Fig. 10-5)

CLASSIFICATION	APPROXIMATE DISTRIBUTION OF LUMINAIRE LIGHT OUTPUT (per cent)	
	Upward	Downward
Direct	0–10	90–100
Semidirect	10–40	60–90
General diffuse	40–60	40–60
Semi-indirect	60–90	10–40
Indirect	90–100	0–10

Installations often are classified according to the light distribution characteristics of the luminaires employed:

Direct lighting is the type of system in which light is distributed downward by the luminaire to the work plane only. (See Fig. 10–5.) Space between and above luminaires may be left dark by this type of distribution. Direct lighting, which was one of the first ways developed for applying electric illumination, provides maximum work-plane illumination. In many cases a direct lighting system is the least expensive.

Disturbing shadows may result unless the area of the luminaires is relatively large or the luminaires are placed relatively close together. Shadows are at a minimum when the luminous area is largest, as with the so-called skylight or lighthood types. Direct and reflected glare may be distressing. In making installations care should be taken to avoid glare and excessive contrasts between the light source and its background.

There are two direct-luminaire types: *distributing* and *concentrating*. The distributing types include reflectors and diffusers with surfaces of procelain-enamel, white baked synthetic enamel, diffuse aluminum, prismatic glass, and silver-mirrored glass. The "shielding angle" of a direct type fluorescent - lamp luminaire should be not less than 13 degrees below the horizontal. More shielding is desirable for filament-lamp equipment. The "cut-off angle" of a filament-lamp luminaire is measured up from the vertical. Widespread light distribution which can be obtained also with aluminum, mirrored-glass, and prismatic-glass is advantageous in many applications in which the seeing tasks are in vertical or near-vertical planes.

In most areas distributing units provide adequately uniform illumination when they are spaced a distance not exceeding the mounting height above the floor; exceptions include areas of high ceilings or high bays.

Concentrating direct-lighting luminaires include prismatic glass, mirrored-glass, and aluminum reflectors. These are used in narrow high bays and in industrial craneways where it is necessary to mount the reflector at a height equal to or greater than the width of the area to be illuminated. In such areas, a concentrated beam directs light to the working area without excessive absorption by walls or unshaded windows. Spacing should provide uniform illumination over the working area. Similar luminaires, sometimes equipped with louvers, are used to provide supplementary lighting on specific work areas.

Semidirect lighting is a natural evolution of direct lighting. Candle-, kerosene-, and gas-flame luminaires were of this type. The design of semidirect luminaires sends 10 to 40 per cent of the light flux upward. This helps to tie together all parts of the room as an architectural whole, and to reduce the contrast between the luminaire and its background. (See Fig. 10–5.) For the most part, luminaires in this class are of the open-bottom type, though some have closed bottoms of glass or plastic material. They are used for localized general lighting in many general-occupancy areas such as stores and also in service areas including corridors, stairways, washrooms, and locker rooms.

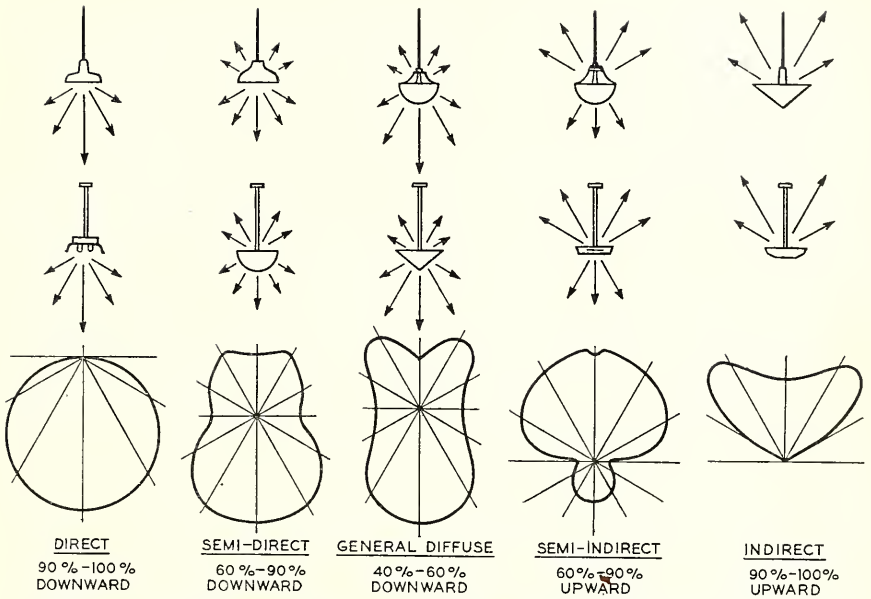


FIG. 10-5. Characteristics of the luminaire distribution classifications established by the International Commission on Illumination (I.C.I.).

General diffuse lighting makes light available about equally in all directions. Brightness uniformity is improved, and luminaire-background contrasts are reduced. Luminaires in this category include incandescent lamp enclosing-globe and fluorescent-lamp types. (See Fig. 10–5.) Globes should be of a density sufficient to provide completely diffuse distribution. The surface area of luminaires should be sufficient to reduce their brightness to within one-twentieth that of the background. The "direct-indirect" luminaire that directs about half its output upward and the remainder downward with little or no horizontal component often falls into this classification. General diffuse lighting systems give more illumination for a specified wattage than do indirect or semi-indirect systems, but cause more noticeable shadows and may cause both direct and reflected glare.

Semi-indirect lighting is a compromise between direct and indirect lighting. The direct component of semi-indirect luminaires is made as great (up to 40 per cent) as the installation efficiency requires and is balanced with the indirect component which may be as great (up to 90 per cent) as the brightness and illumination uniformity of the installation requires. Both semi-indirect and indirect lighting light the ceiling and upper walls. (See Fig. 10–5.)

In general, semi-indirect types have a larger utilization coefficient than do indirect units. More attention must be given to the factors of direct and reflected glare but less than to semidirect or direct types. Luminaires of this and other classifications are available in completely enclosed types,

which resist the collection of dust and dirt and are easily cleaned. Also there are styles that are open at both top and bottom so that only the upper surface of the lamps remains to collect dust and dirt. The reflectance of the ceiling should be maintained as high as practicable when semi-indirect or indirect luminaires are utilized.

Indirect lighting is the type wherein the output of a luminaire is diffused and redistributed by a large intermediate surface (usually a ceiling). Indirect lighting is less efficient than most direct lighting because of the absorption of this redistributing surface, but it is a common means of getting very uniform levels of illumination. (See Fig. 10-5.) The permissible brightness of the intermediate surface and relatively low efficiency achievable limit its use. Ninety to 100 per cent of the light from indirect luminaires is first directed to the ceiling and upper wall areas, from which it is reflected diffusely to all parts of the room. Usually only enough light is emitted below the horizontal to raise the luminaire brightness to match that of the ceiling.

One measure of the quality of lighting which a given source will produce is the angle subtended by the source at the point of work. With three-dimensional work tasks, particularly of a specular or semispecular nature, this factor is particularly important. The most common large-area source is an indirect-lighting system. In effect, the entire ceiling and upper wall areas become a light source. If the brightness is uniform and approximately equal to that of the luminaires, with such a large area serving as a source of light, little direct glare is experienced at illumination levels up to about 50 footcandles. Shadows are practically eliminated and reflected glare reduced. As with semi-indirect luminaires, ceiling reflectance must be maintained high because at best this type of system is likely to be the least efficient. Specular and semi-mat-finished configurated ceilings have been developed for use with indirect-type luminaires to present reduced brightness at normal viewing angles. For many locations where indirect lighting is impractical there are available special luminaire types which produce somewhat the same effect. They consist of large luminous areas placed relatively close to the visual task, as in Fig. 10–6. The angle subtended by the luminaire is of the same order of magnitude as that subtended by an indirectly lighted ceiling.

LIGHT AND ARCHITECTURE

The typical luminaire may not be considered an architectural element by most illuminating engineers, but, regardless of terminology, lighting is so integrated with a building's use and appearance that it always should be given consideration in all stages of architectural design and decoration development. Active co-operation between architect and engineer is insurance against practical difficulties. Lighting can become the basic decorative or appearance motif, as well as a necessary working tool and an aid to comfort and safety in any interior.

Such structures as churches, theaters, and public buildings, usually can

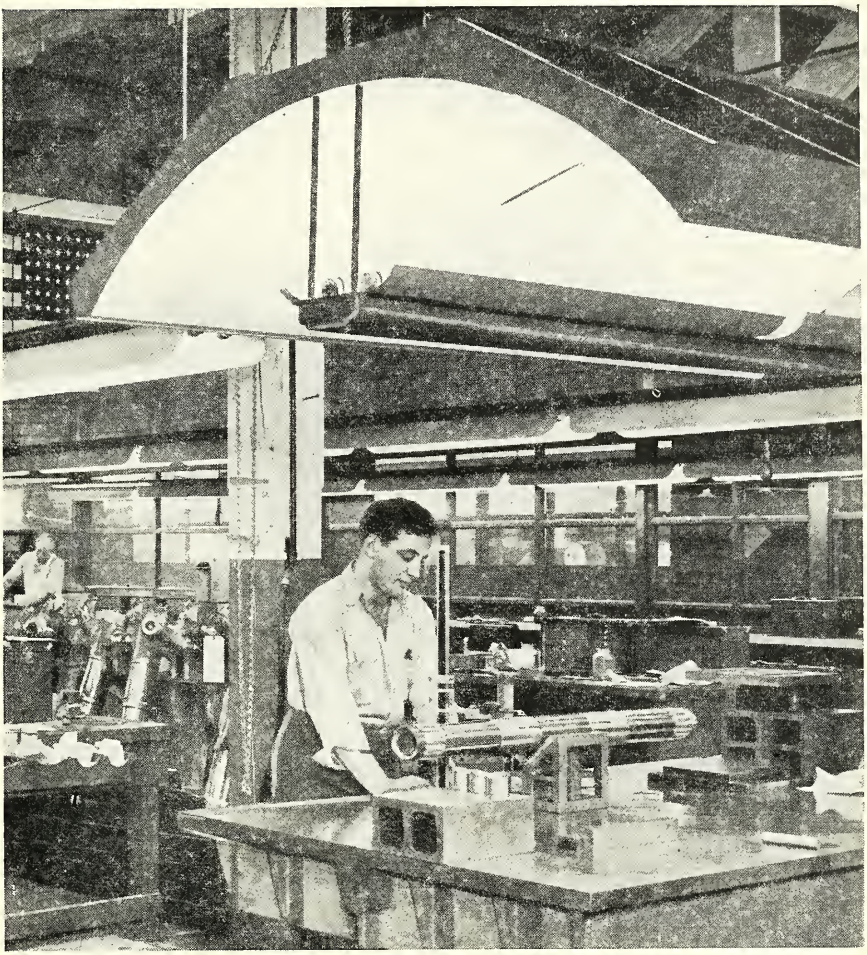


FIG. 10-6. For maximum visibility of specular surface detail, general illumination is supplemented by light from large-area, low-brightness luminaires.

not have their lighting classified simply as direct or indirect. They often are provided with more complex systems. Architectural planning of many of these structures involves traditional style and period considerations. The lighting design should be developed with full recognition of these considerations. Similar thinking sometimes is applied to other interiors, including homes, sales areas, and office and management areas of industrial plants. This architectural thinking encompasses hanging and surface-mounted as well as built-in luminaires and calls attention to the value of considering all types of lighting equipment integral parts of a structure, at least equal in importance to other elements.

Luminaires should be related to the architectural motif of the building and should assist in carrying out an architectural plan. This is equally true of period and modern design.

Table 10-2. Styles and Lighting Effects of the Architectural Periods*

PERIOD	ARCHITECTURAL STYLE	NATURAL LIGHTING EFFECTS†
Greek 700–146 B.C. Orders: Doric, Ionic, Corinthian Important buildings: Temples	Column and lintel, with entablature. Harmony of design so as to obtain perfect balance between horizontal and vertical elements. Perfect proportion, simple decoration	Emphasis on the statue of the god or goddess to whom the temple was dedicated. Light was obtained from roof openings usually over the statue, or from clerestory openings, or from doorways. Temples were usually oriented so that the rising sun might light up the statue. Direction of incident light mainly from above, at oblique angles
Roman 146 B.C.–365 A.D. Orders: Tuscan, Doric, Ionic, Corinthian, Composite Important buildings: Temples, basilicas, thermae (baths), palaces	Column and lintel, with entablature. Arch developed. Vault and dome evolved. Elaborate decoration	The Romans used windows extensively. They obtained light by means of clerestories, openings in the center of domes, or windows at the base of domes. Direction of incident light mainly from above, at oblique angles. Light used to enhance the elaborate decoration and majestic proportions of interiors
Early Christian 300–900 A.D. Important buildings: Basilican churches	Column and lintel, with a long interior perspective. Occasional domes and rotundas supported on arched colonnades	Oblique lighting from upper angles obtained through clerestories and window openings, usually small. Emphasis on altar obtained by columnar perspective as well as the convergent perspective of windows in clerestories. Glass mosaics reflecting light often used for the high altar
Byzantine 324 A.D. Important buildings: Churches	The dome on pendentives is the main feature of Byzantine architecture. In Roman architecture domes were used only over circular or polygonal buildings, but in Byzantine architecture domes were placed also over square structures. Here the earlier horizontal motif changes almost imperceptibly to a vertical motif	Lighting from upper angles obtained through windows at the base of domes. The dome being highly illuminated acted as a huge reflector. Small glass and translucent marble windows prevented glare and added color to the interior. Brilliant mosiacs glowed with numerous subdued reflections. To relieve their flat wall decoration, the Byzantine builders obtained "depth" by means of arcades

Table 10-2—Continued

PERIOD	ARCHITECTURAL STYLE	NATURAL LIGHTING EFFECTS†
Romanesque 800–1200 A.D. Important buildings: Churches, castles	Massive Roman walls coupled with the round arch	The effect of solemnity and vastness was produced by the contrast between great wall spaces and small windows. Such windows, single or grouped together, admitted rays of light through clerestories
Gothic 1200 – 1500 A.D. Important buildings: Churches, monasteries, castles, mansions, town halls	This aspiring style with its pointed arches definitely introduced the vertical motif. Solids prevailed in Roman architecture, but in Gothic architecture voids prevailed instead, since slender buttresses were used instead of massive walls	In churches the mood of solemnity was produced by the lofty, dimly illuminated ceiling, while long rays of light penetrated stained glass windows. In castles and manor houses larger windows than ever had been used before in domestic architecture became the vogue
Renaissance 1400–present day Important buildings: Churches, castles, town halls, palaces, villas, chateaux, civic buildings	The rebirth of classical ideals brought the ideal of architectural harmony again into vogue. Buildings were so designed that the vertical and horizontal members obeyed the classical laws of proportion. For decoration Greek and Roman details were copied	Lighting effects became more numerous to suit different types of buildings. Domes were supported on "drums" which were pierced with large windows. The dome lighting of the Byzantine period was revived and improved. The direction of incident light was still mainly from above, though lower windows also were enlarged. Windows became more numerous, and more light was sought than before
Modern (twentieth century) All types of buildings	The twentieth-century style strives for structural logic. For skyscraper design the the vertical motif is emphasized. For smaller buildings the supporting steel structure is not camouflaged but rather is incicated by simple "wall lines" and other decorative devices. Stone, glass, chromium, and other metals are used without elaborate ornamentation	Electrical illumination now is recognized as an architectural medium. Modern lighting systems vary from the layout with outlets located with mathematical symmetry to the decorative system with light sources in arcades, columns, recesses, panels, cornices, coves, wall pockets, urns, etc. Luminaires differ widely in design and in material

*D'Andrade. H. E., *Lighting and Lamps*, 1943.

†Some use was made of flame sources (wooden torches, tapers, candles, and oil and gas lamps) even in very early periods. The design of luminaires in period interiors frequently follows the pattern established by the characteristics of these early lamps.

Since the effect of daylight entering through openings such as ceiling apertures, skylights, and windows was utilized by even the earliest architects, traditional designs may require a simulation of these elements. Luminaires designed in an attempt to recreate such effects should distribute their light in a similar manner. The movement of the sun in the sky produced a variation of effect during the day and from season to season, but, in general, some specific orientation was considered as a basis for architectural design. Once an orientation is selected, electrical lighting can readily duplicate (in many cases can surpass) natural-lighting effects because of its susceptibility to intentional variation and control. Structural and ornamental details of a luminaire as well as its light-distribution characteristics should conform to the architectural motif. Some of the characteristics of the architectural periods are summarized in Table 10–2 and in Fig. 10–7.

Dual Installations

Many plans for traditional and monumental interiors use two quite separate lighting systems. In a single interior one group of luminaires may be installed largely for appearance' sake, while the other group, wholely or partly concealed, provides utilitarian illumination. The architect may prepare aesthetic specifications for fixtures that appeal to him as good looking and appropriate, and establish the mounting height he knows is correct for the sake of appearance. At the same time, the engineer provides most of the illumination needed by means of unobtrusively located utilitarian luminaires, placed where they will best provide the desired amount of light, of the proper color and other qualities.

Built-in Luminaires

Important departures from traditional design have helped to bring into being many interesting modern-lighting installations:

An important contribution to the closer work of the two professions is the type of luminaire which, in conjunction with near-by ceiling or wall areas, provides wide bands, ribbons, panels, or disks of light, all of relatively low surface brightness, and with dimensions that the architect selects.

Some of the common built-in lighting forms are described in the following paragraphs. Design and calculations data on some of these devices will be found in Table 8–12, (page 8–34).

Luminous cornices are luminous panels located at beam or wall intersections with the ceiling (Fig. 10–8).

Downlighting is a special term used to describe a direct-lighting system in which light emanating from above the ceiling line, controlled above or at the aperture by a recessed reflector, lens, or louvers, is projected through an aperture to the area to be illuminated (Fig. 10–9).

Cove lighting is the term applied to sources concealed by a cove, ledge, or horizontal recess from which light is distributed over wide areas of ceiling space to be redirected downward (Fig. 10–10).

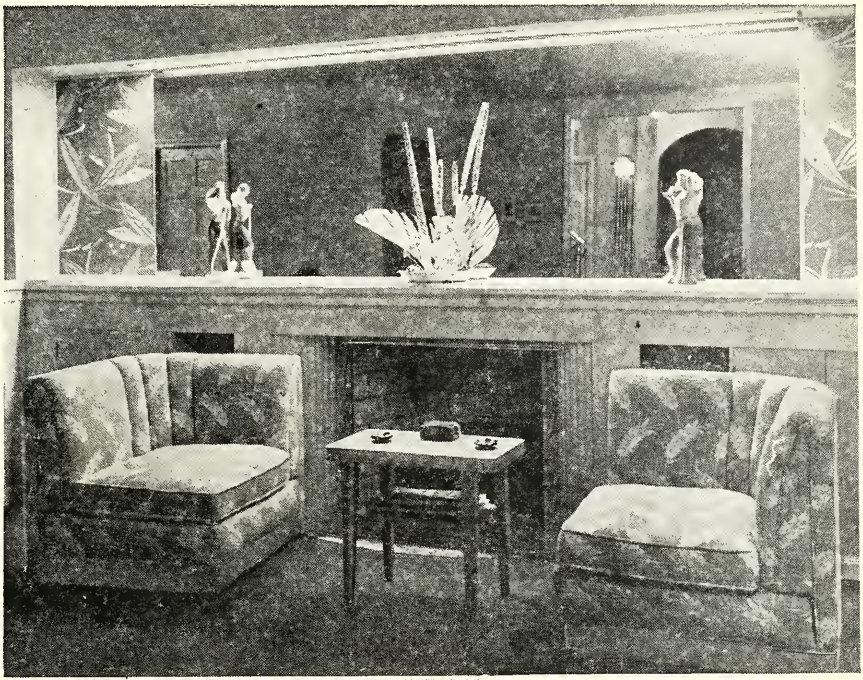




FIG. 10-7. Two contrasting period interiors: contemporary (above); Louis XVI (at left).

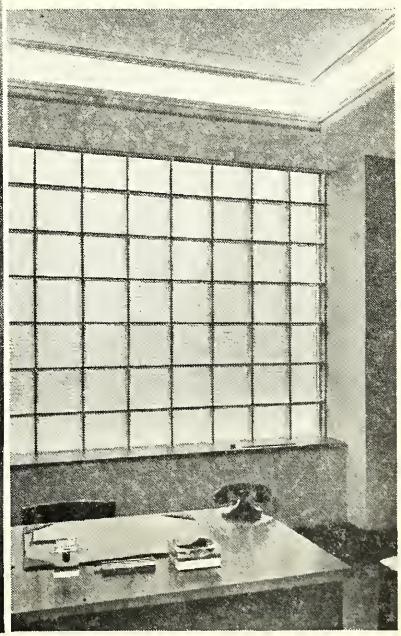


FIG. 10-8. Luminous cornices.

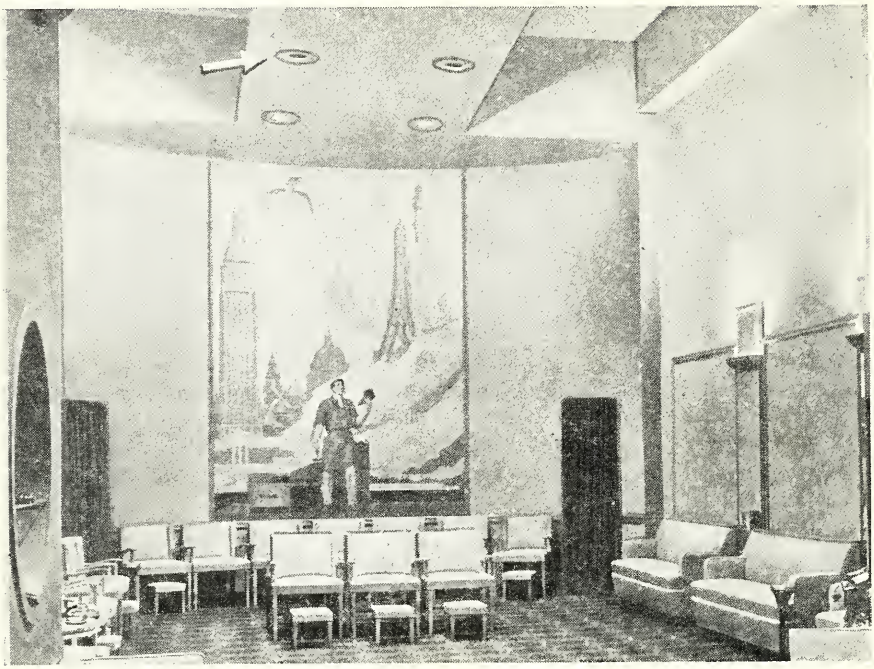


FIG. 10-9. Downlighting.

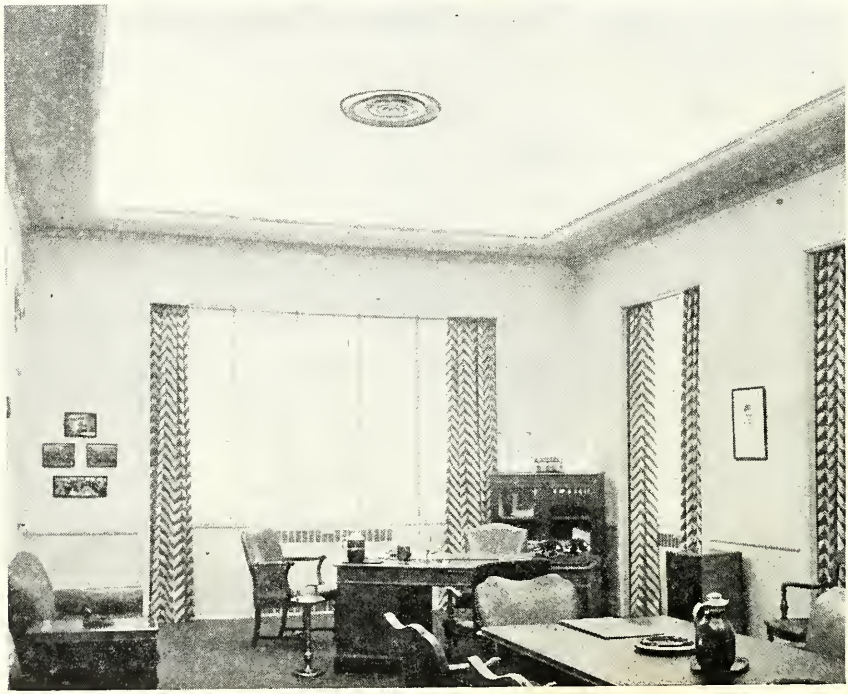


FIG. 10-10. Cove lighting.

Luminous beams incorporate light sources in translucent plastic or glass forms (Fig. 10–11). When not illuminated they resemble steel, wood, or plaster beams.

Luminous panels are large luminous areas resembling skylights (Fig. 10–12).

Luminous coffers or troffers are recessed ceiling areas lighted by centrally or edge placed lamps (Figs. 10–13 and 10–14).

Artificial skylighting utilizes luminous panels constructed and installed so as to imitate a natural skylight. In some cases light sources are mounted in a natural skylight for use on dark days or at night (Fig. 10–15).

Luminous tubing usually describes hot- or cold-starting, low-current density fluorescent lamps or tubes which are used exposed or with very simple decorative or diffusing mediums to create light lines or patterns on ceilings or side walls (Fig. 10–16).

Luminous elements include all of the forms mentioned as well as other unclassified combinations of lamps, diffusing mediums, and structural features that usually provide decorative effects and sometimes contribute substantially to the general illumination.

Wherever the lighting equipment is to be planned as an integral part of a structure, it is necessary that the architect provide adequate space to house lamps and control equipment. Figure A-1, Page A-10 provides useful data for estimating the general illumination which may be provided in open interiors by a range of wiring capacities serving various types of light sources and luminaires.

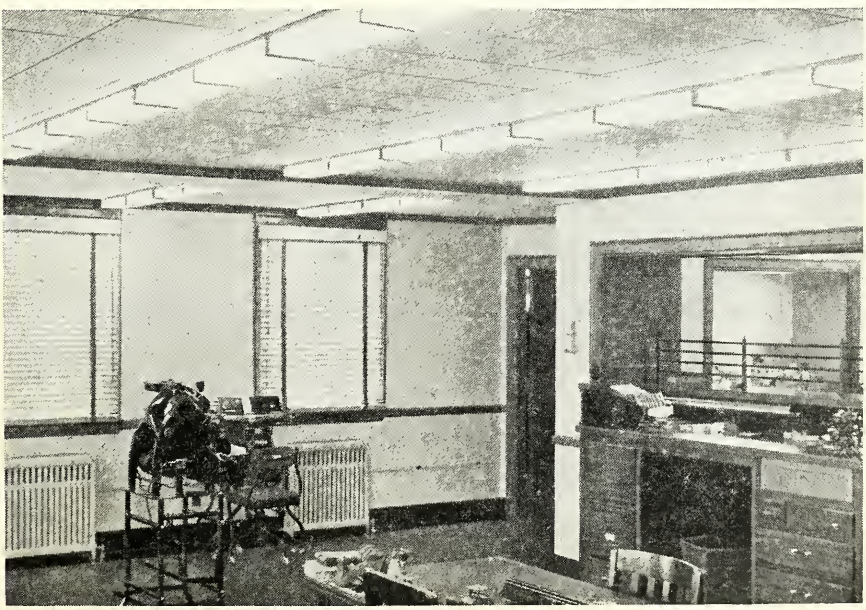


FIG. 10-11. Luminous beams.

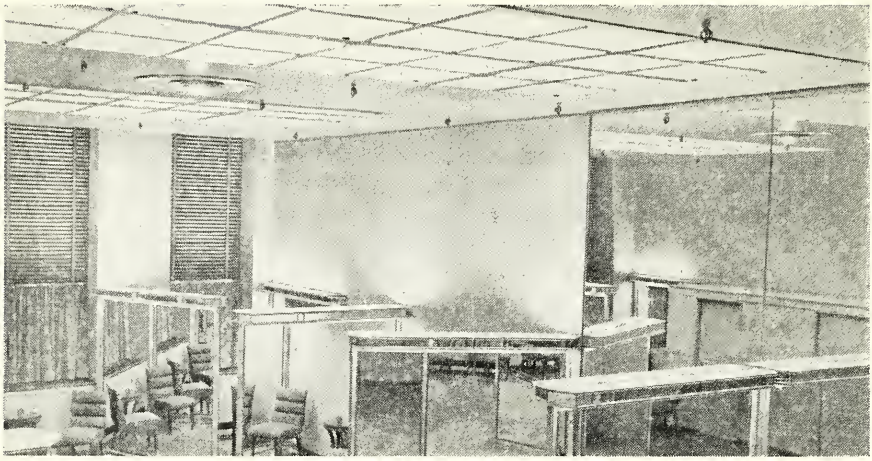


FIG. 10-12. Luminous panels.

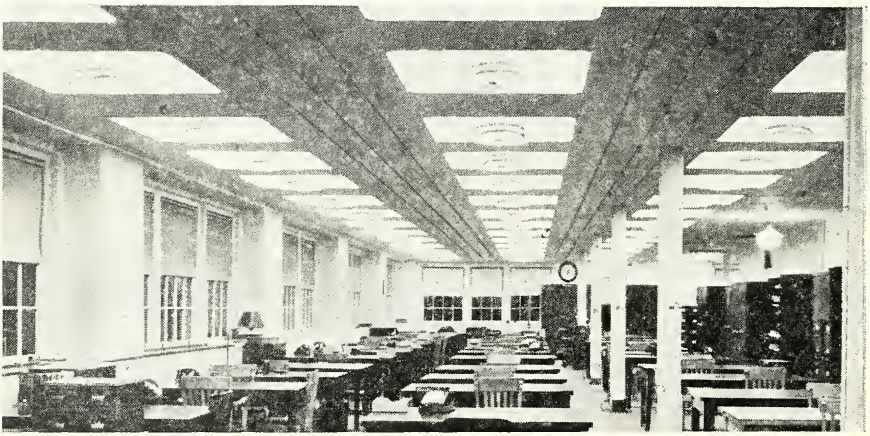


FIG. 10-13. Luminous coffers.

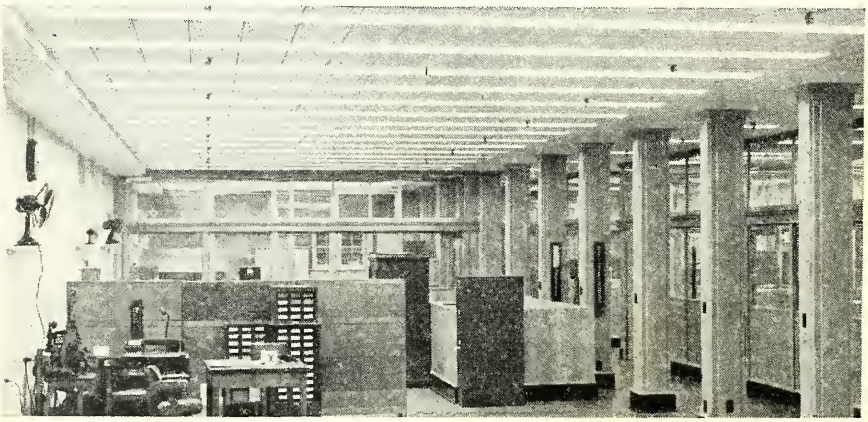


FIG. 10-14. Troffer lighting.

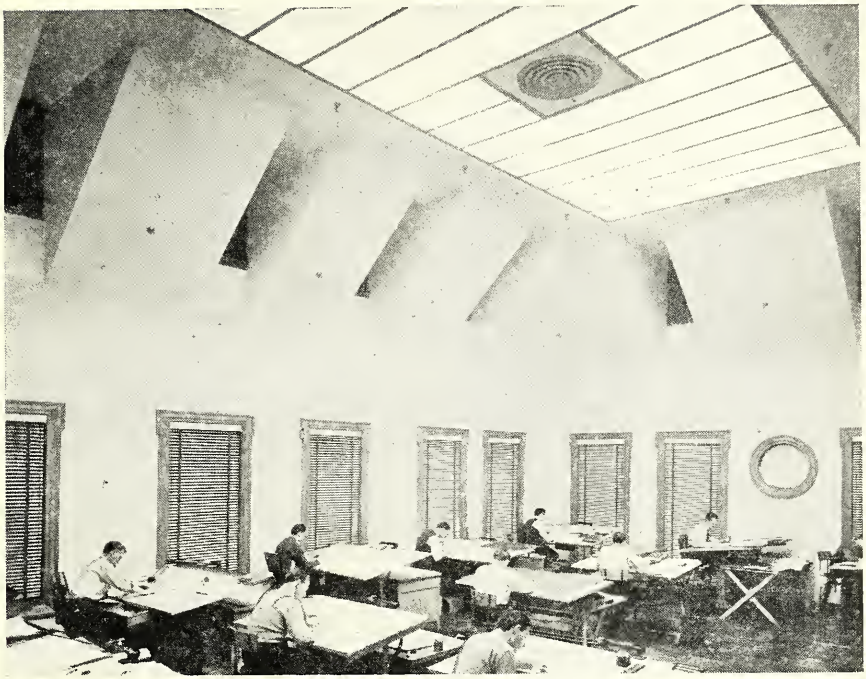


FIG. 10-15. Artificial skylighting.

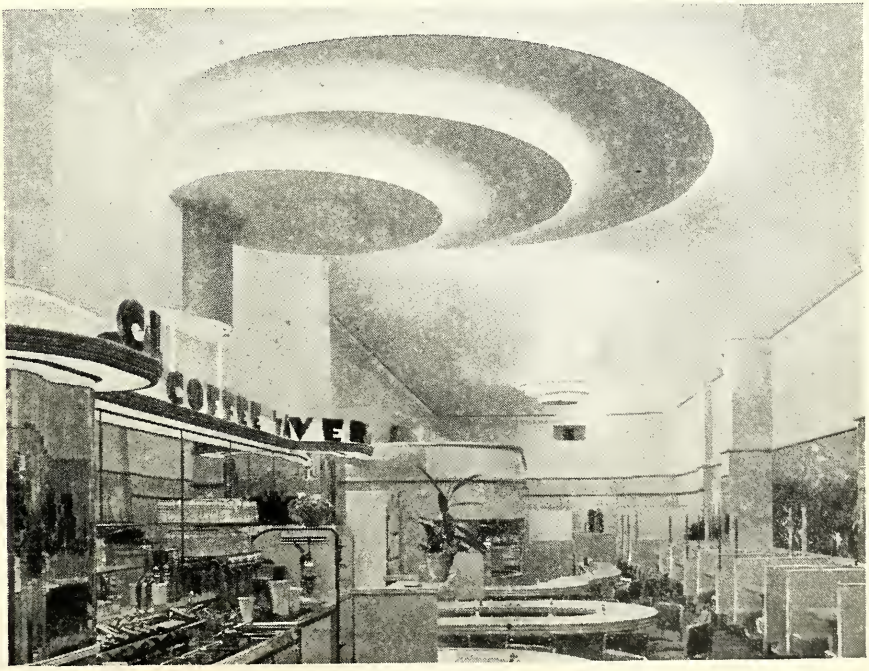


FIG. 10-16. Luminous tubing patterns.

LIGHTING-APPLICATION TECHNIQUES

Interior-lighting applications may be divided, for convenience in discussion, into six broad classifications: residence (including farm), office, store, school, public building, and industrial lighting. Although these classifications are not mutually exclusive and no sharp lines of distinction exist between them either in theory or in practice, their practical objectives may be quite different as, for example, the lighting of stores and offices. Physical differences (the average living room compared with an automobile-assembly plant), emphasis on utility or decoration (the warehouse compared with the theater), and the variation of seeing task severity (the watch factory inspection department versus a night club corner table) have inspired the development of application techniques which are known as "current practice" in each of the six classifications. The specific techniques are discussed in some detail in succeeding subdivisions of this section.

No summary of the considerations involved in any single interior is a sufficient guide for planning and designing all lighting installations. The following, however, should be weighed carefully in planning any lighting installation:

Quantity of Illumination

The primary standard of lighting effectiveness is the illumination level. Other factors held constant, increases in illumination level are accompanied by increases in visual acuity. With an acknowledgment of the limitations imposed by other factors, levels of illumination have been recommended by the Illuminating Engineering Society for many of the common seeing tasks encountered in each of the application fields. (See Table A-1, page A-1.) The tabulated illumination levels are neither minimums nor maximums, although they tend toward the former. They are found in the common practice of the day, which reflects a balance of many variables, including economic factors, convenience, and availability. The recommendations are reviewed periodically and when, because of new knowledge and practices, a change appears in order, a revised table is published.

The scientific basis for appraising a seeing task involves four interrelated factors: (1) the size of the object to be viewed; (2) the brightness contrast between the object and its immediate background; (3) the time available for seeing; and (4) the average brightness of the object. Usually, the first three factors are constants in a specific lighting problem and only the fourth factor is chosen by a designer. Brightness equals the illumination (a controllable factor) times the reflectance of the seeing task. The importance of proper interpretation of illumination tables is evident.

Quality of Illumination—Brightness Levels

The provision of adequate levels of illumination does not guarantee comfort. Vision is not a mechanical process and therefore thought should be given to those factors that physically or psychologically contribute to the satisfaction of using the lighting. Such terms as "glare" and "shad-

ows" are manifestations of these factors. A popular definition of glare is "light out of place."

The Illuminating Engineering Society has established Brightness Standards for schools, homes, and offices based on the best data presently available. These standards are described on pages 10–52 and 10–76.

The theories are discussed in Section 2. Data regarding calculation procedures are given in Section 8.

Light Source Selection

The characteristics of applicable light sources are important factors in lighting design and influence luminaire selection. Usually there are several light sources which can be applied in each lighting field. In some cases, however, a particular characteristic may be so important that a source strong in that capacity may meet the requirements best, despite other limitations. For example, a long-life lamp may be absolutely necessary for those places where replacement problems are very difficult. When there is a limited power supply or wiring capacity or very high power costs, a light source having a high over-all lumen-per-watt rating is particularly desirable.

Luminaire Selection

Before lighting calculations are made, a type of luminaire should be selected for preliminary consideration. The characteristics of different types of luminaires are described on pages 10–5 to 10–8. Luminaires are classified according to their light distribution characteristics and also according to their principal field of application, e.g., the *industrial* unit. This latter classification usually depends on the appearance, mechanical construction, and installation method and sometimes upon the electrical characteristics of the luminaire.

In many cases, several types are available and the final selection may be made on the basis of overall cost and appearance.

Luminaire Layout

The determination of the illumination level and the type of luminaire permits consideration of the luminaire layout. Lighting levels (both high and low) and other factors occasionally restrict the type of equipment which may be chosen and its installation arrangement, but in most cases the advantages of a general, local, localized-general, or a general-plus-supplementary plan should be weighed. (See page 10–3.)

The *individual electric outlet layout* plan is a basic method with incandescent-lamp luminaires because of the symmetrical lateral light distribution characteristic of most equipment of this type and because of the economy and practicality of concentrating lamps of high rated wattages in single units. The most common plan consists of a symmetrical arrangement of one to four luminaires in a bay (or room). To a large extent, early fluorescent installations followed this same technique. However, the present trend is to emphasize their linear characteristic and the result is a growing number of light patterns based on *straight line elements*.

Even where fluorescent luminaires are suspended below individual electrical outlets, they may abut each other and be connected physically and electrically. Since common four-outlet-per-bay layouts usually call for 10- by 10-foot or 12- by 12-foot spacing, it is readily appreciated that combinations of 4 foot, 5 foot, and longer elements can bridge such spaces readily. Inherently, fluorescent lamps are of low lumen output per foot. The 40-watt lamp and its ballast consume together about 12 watts per foot. Thus, a greater luminous area and usually a larger number of lamps are needed to provide a given illumination level with fluorescent lamps than with the higher wattage incandescent lamps, despite the greater efficiency of the former.

Lines and geometric patterns of fluorescent-lamp luminaires often are surface-mounted on the ceiling, suspended from it, or recessed in it. The low operating temperature of the fluorescent lamp, the value of diffuse-light distribution, and the harmonious architectural lines that such an approach creates, all have resulted in increasing emphasis on such patterns.

MAINTENANCE OF LIGHTING

Maintenance is a most important factor in the effectiveness of any lighting installation. In its broadest sense it includes everything connected with maintaining the output of a lighting system as near to its initial level as possible. Systematic maintenance plans should form a part of every installation design involving a large number of lamps. Today increasing recognition of the importance of maintenance is resulting in the development of specialized lighting-maintenance-service organizations.

Incandescent-Lamp-Luminaire Maintenance

In an incandescent-lamp luminaire, sometimes only the lamp itself is considered an essential operating part requiring regular replacement; however, the reflecting or other control medium also may be very important. When there is a factor of permanent or accumulative depreciation to be considered in these other parts (as contrasted with dirt which, hopefully, is considered temporary depreciation), provision should be made for their replacement also. Such depreciation is not necessarily a sign of poor design, although good design tends to minimize it.

In addition to the dirt problem, the incandescent lamp, like other light sources, presents two other maintenance problems: output depreciation and failure to operate. Output depreciation is an inevitable condition of operation, although in some cases (e.g., series operation of street-lighting lamps) it may not be of concern from a maintenance standpoint because of compensating factors which are designed into the system. In designing installations, output depreciation is included in the original calculations in order to allow for the expected reduction in performance caused by operating conditions.

When an incandescent lamp fails to operate, replacement is necessary. In many installations this is done on a "hit-or-miss" basis. In larger

installations some attempt is made to schedule the procedure, to reduce the labor cost, and to provide less interference with other operations in the room. The system may be based on a periodic check and replacement, or on a scheduled replacement of all lamps in a particular area regardless of their operating or appearance status. The latter is termed *group replacement* and is based on the premise that the saving in cost of replacing lamps is greater than the value of the remaining light output in a large group of lamps after a certain number of hours of operation. This "smash point" usually is considered as falling between 60 and 80 per cent of rated lamp life. Generally it is assumed that the relatively few early failures that occur can be ignored, since they will not appreciably affect the average illumination level.

Fluorescent-Lamp-Luminaire Maintenance

Fluorescent-lamp luminaires present problems similar to those of the incandescent-lamp type, although certain differences are noteworthy. First of all, the rated lamp life usually is longer, although usually there are many more lamps used in a given area because of the relatively low lumen output per lamp. Second, when luminaires are above head height, it is very difficult to replace lamps without lowering the luminaire or elevating the maintenance man. Third, the required circuit ballast and starting accessories, which must be maintained also, often are responsible for the inoperative lamp. Group replacement is feasible and highly desirable for many types of fluorescent installations. Cut-out starters are recommended for preheat-starting circuits, particularly those maintained on a group basis, since otherwise the constant on-and-off flashing characteristic of many early fluorescent lamp failures may not only be annoying to persons in the area but also harmful to ballasts. The larger the area lighted by a single tube or lamp, the more important it is to have a replacement immediately.

Depreciation

Dirt depreciation is a function of the following variables:

1. Room occupancy: some types of surroundings are dirtier than others.
2. Luminaire design: particularly the dirt-collecting characteristics of reflecting and transmitting surfaces.
3. Air movements in the room and in the luminaire.
4. Nature of the dirt in the area.

Dirt is a cause of poor appearance and poor sanitation as well as of inefficiency. To justify its cost, removing dirt should result (and usually does result) in improvements of equal or greater economical consequence. Figure 10–17 shows details that were calculated for a specific luminaire installation and fixed operating conditions. For any luminaire and application condition similar graphs can be prepared in which the loss of light caused by a particular percentage of dirt is evaluated in terms of over-all operating costs and the cost of each cleaning. If in a given time the loss of

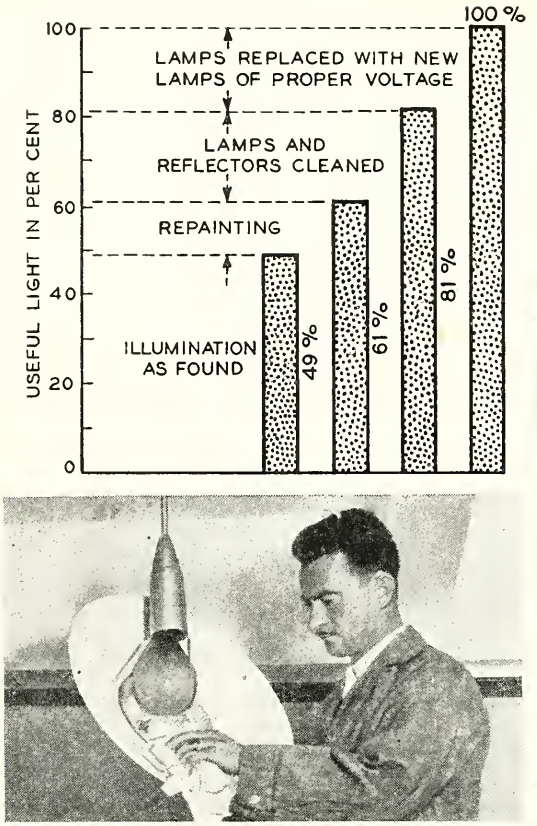


FIG. 10-17. Increased reflectances, improved brightness ratios, and higher illumination levels may be obtained by simple maintenance procedures.



light (evaluated in dollars) is greater than the cost of cleaning, it is economically sound to decrease the time interval between cleanings. As the individual cleaning cost increases, a longer period between cleanings is justified.

The cost of cleaning will vary depending on local labor rates; on the luminaire design, its mounting height and location, and the physical difficulty of reaching it and of cleaning it in place, or of disconnecting it for cleaning at floor level or elsewhere; and upon the possible interruption in other operations that the operation may make necessary.

Cleaning Materials, Equipment, and Procedures

Most cleaners will not harm glass surfaces. However, care must be taken in cleaning metal reflectors, since both alkali and acids may attack the metal, causing roughness, pitting, etc., and thus reduce the reflectance of the surface and cause it to collect dirt faster. Wax or wax-emulsion cleaners leave a thin wax film on a surface which eases subsequent cleaning and helps to retain high reflectance.

When reflectors or glassware can be taken down for cleaning, the following procedure is recommended:

1. Immerse parts in a cleaning solution and scrub with sponge or soft brush.
2. Rinse in clear warm water.
3. *Do not immerse* lamp bases or any electrical connections.

When reflectors or glassware cannot be taken down, wash with a cleaner that requires no rinsing, and wipe off excess moisture with a clean cloth.

A cleaning truck is shown in Fig. 10–18.

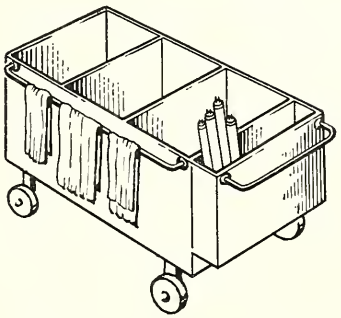


FIG. 10-18. A luminaire maintenance truck or wagon with compartments for cleaner, rinse water, rags and lamps.

Practical methods of reaching lighting equipment. Table 10–3 will aid in the selection of suitable lighting maintenance equipment.

Pole lamp-changers. The simplest type of lamp-changing device is the clamp grip mounted on the end of a pole as shown in Fig. 10–19. In many industrial plants with installations of open-bottom, vertically-mounted, incandescent-lamp luminaires, pole-changers are used between periods of regular maintenance for emergency lamp replacement. For recessed reflector lamps this device is particularly well suited since, no other special maintenance equipment will be required.

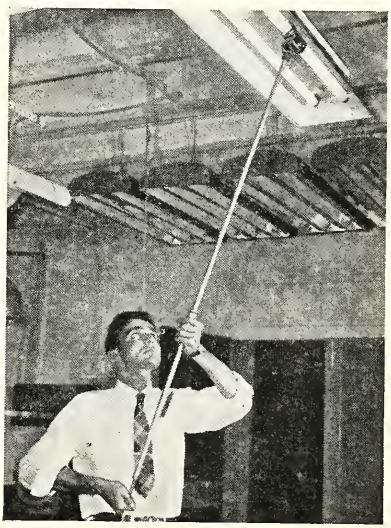


FIG. 10-19. A pole-type lamp-changer.

Disconnecting and lowering hangers. Disconnecting and lowering hangers offer many advantages for safe, economical maintenance of lighting equipment. With such hangers the luminaire can be lowered to the floor by means of a permanently fastened chain or cable. (See Fig. 10-20.) Usually the chain is carried to some convenient location where it is out of the way until needed. When the reflector is lowered the electrical circuit is broken. After the reflector has been cleaned and relamped, it is pulled back into place, where it automatically locks into position, reestablishing the electrical circuit.

Stepladder. For relatively low mounting heights, stepladders are used because of their convenience and portability. Clips and hooks which hold

Table 10-3. Typical Maintenance Devices for Various Luminaire Mounting Heights

TYPE OF EQUIPMENT	LUMINAIRE MOUNTING HEIGHT			
	Up to 12 ft	12 to 18 ft	18 to 30 ft	Above 30 ft
Pole lamp-changers	X	X	—	—
Disconnecting hanger	—	—	X	X
Stepladder	X	—	—	—
Straight ladder	—	X	—	—
Portable maintenance platform	—	X	X	—
Crow's-nest ladder	—	—	X	—
Telescoping platform, elevating tower, etc.	—	X	X	—
Catwalk or truss (fixtures swing in)	—	—	X	X
Crane or Relamping bridge	—	—	X	X



FIG. 10-20. Disconnecting and lowering hangers. Inserts show disconnect housing and lowering crank.

spare lamps and cleaning rags enable a man to do an entire cleaning and relamping job with one trip up the ladder. (See Fig. 10–21.) Where reflectors are removable the following procedure is recommended:

1. Clean the spare reflector (or the set of light control parts); carry the clean parts up the ladder.
2. Hook the clean reflector to the ladder while disconnecting the dirty one.
3. Install the clean reflector.
4. Bring down the dirty reflector; clean and use it in similar fashion at the next outlet.

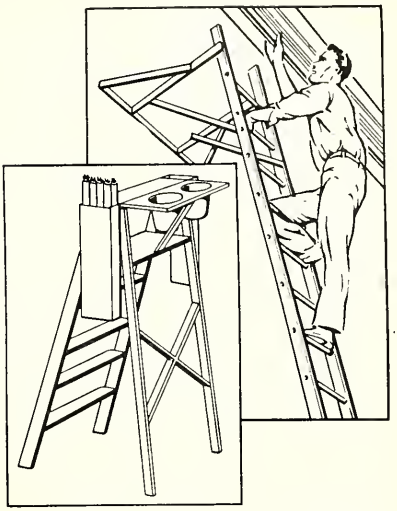


FIG. 10-21. Luminaire-maintenance ladders.

In many cases where the entire installation is cleaned at frequent intervals specially designed cleaning trucks such as shown in Fig. 10–18 are used. Three compartments are useful: one for cleaning solution, one for rinse water, and one for clean rags. If convenience outlets are installed throughout the area, both cleaning solution and rinse water can be kept hot with immersion heaters.

Wherever possible, luminaires should be cleaned at floor level because a more thorough job can be done, greater safety is assured, and there is less possibility of splashing cleaning solution or rinse water where it is not wanted.

Straight ladder. In some cases ordinary ladders can be modified slightly to meet specific reflector mounting conditions. For example, a lightweight brace mounted on the end of a ladder, when placed against a beam, may provide the maintenance man more convenient access to the luminaires. (See Fig 10–21.)

Portable maintenance platform. These are used where there are a great many luminaires at a given mounting height. (See Fig. 10–22.) These platforms are equipped with castors and the smaller ones can be made so light in weight that one man can handle them without difficulty. The use of such platforms, particularly with continuous-row, fluorescent-lighting installations, permits a man to reach several luminaires safely without changing the platform position. Occasionally, in industrial plants with regularly spaced aisles and equipment serviced from the floor, the platform may be designed to span the spaces bteween adjacent aisles.

Crow's-nest ladder. This type of ladder attached to a truck body has been used for street-lighting maintenance and may be adapted to interior-lighting maintenance in large areas with wide aisles. Trucks are designed with a short wheel base and short turning radius to permit a man on the ladder to reach the entire lighting installation. The crow's-nest ladder shares with other movable platforms the ability to reach luminaires that are located

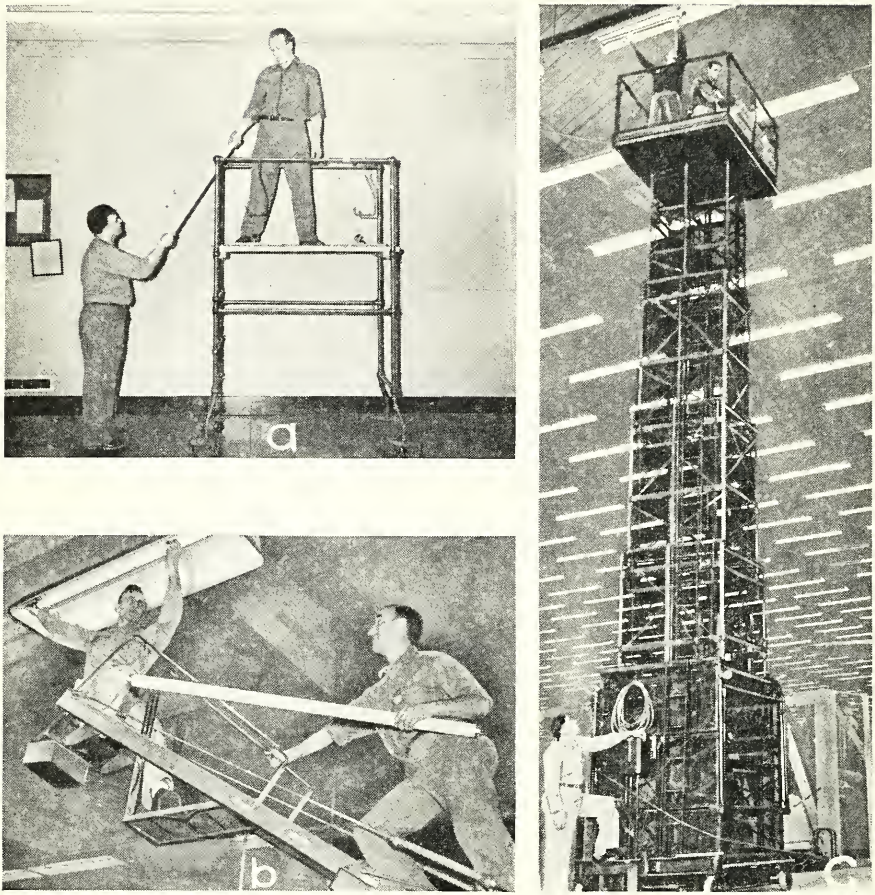


FIG. 10-22. Portable maintenance platforms: a. fixed height type. b. crow's nest ladder. c. telescoping type.

over machinery and other obstacles, since the ladder may swing out at an angle over the side or back of the truck. Hooks and clamps should be attached to the ladder (see the discussion of stepladders) to hold the required spare lamps and cloths. Ladders of this type provide a secure platform to which a safety belt may be attached.

Telescoping platform, elevating tower, etc. Telescoping devices have the advantage of small size when the various extensions are nested together, which permits their passage through low doorways, facilitates storage, etc. They can be designed to reach nearly any desired height. Outriggers which may be folded into the frame while it is in transit give this type of device added stability. (See Fig. 10-22.)

Catwalk or truss. High-bay installations can be designed with luminaires mounted near trusses or specially designed catwalks to which they can be

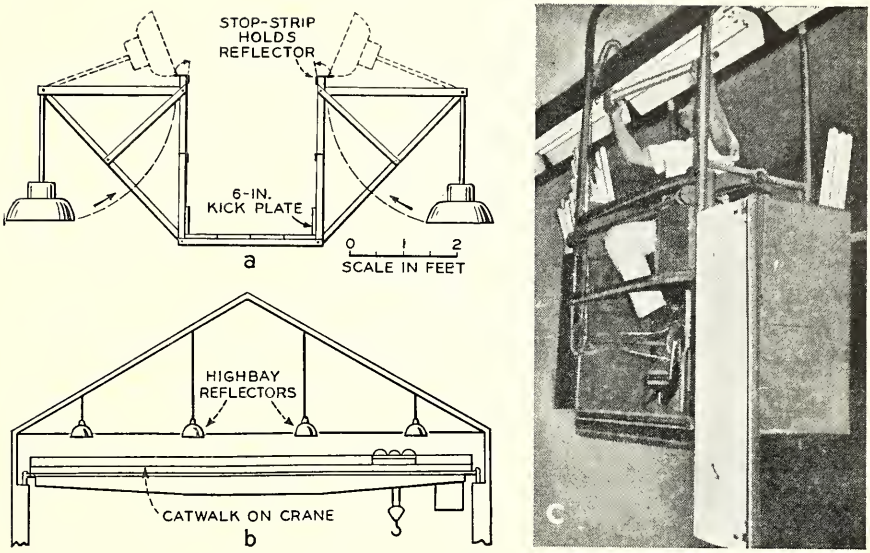


FIG. 10-23. Provision for luminaire maintenance sometimes is provided in building or machinery installation plans. Luminaires may be reached conveniently from (a) catwalks or trusses, (b) cranes, or (c) monorail cars.

pulled with a short hook and secured for cleaning. (See Fig. 10-23a.) This permits a maintenance man to clean and relamp conveniently and safely. The hanger should be designed so that a man may perform his work comfortably and rapidly and with a minimum of physical effort. For example, reflectors at catwalk floor level require bending or kneeling and increase the possibility of dropping cleaning materials or lamps. A kickplate at the edge of a catwalk will catch many things that otherwise might roll off.

Crane. Cranes such as that shown in Fig. 10–23b are utilized for lighting maintenance in many high-bay areas. Attention should be given in planning the original lighting layout and crane facilities to permit convenient access to the reflectors. If the crane is designed to pass just under the lighting equipment, it is desirable to place an auxiliary platform below the maximum elevation of the crane so that the fixtures are approximately 6 feet above the platform. Thus the maintenance man can clean the reflector conveniently and reach the other parts and the wiring. If the roof is a considerable distance above the crane, the reflectors should be suspended within 6 feet of the crane platform upon which the man will stand.

Relamping bridge. In high ceiling areas, where cranes (if they are available) are not to be used for lighting maintenance or where there are overhead monorails, relamping bridges, or cars such as that shown in Fig. 10–23c may be used. These are maintenance platforms designed for ceiling suspension. They may be towed into place; they may be individually operated on the monorail system; or they may be placed in position by the crane. They have been found satisfactory for simultaneous maintenance of relatively large areas.

LIGHTING AND BUILDING CODES

The Illuminating Engineering Society is the recognized authority in the lighting field and has published many *Recommended Practices.* Several are reproduced in condensed form in this handbook.

The complete texts of the following may be obtained from the I.E.S. General Offices, 51 Madison Avenue, New York 10, in booklet form:

American Standard Practice of School Lighting.
Recommended Practice of Office Lighting.
Lighting Practices for Stores and Other Merchandising Areas.
Recommended Practice of Home Lighting.
American Recommended Practice of Industrial Lighting.
American Standard Recommended Practice of Street and Highway Lighting.

LIGHT AND AIR-CONDITIONING

Since any light source adds to the total heat in the interior in which it is operated, to the extent of 3.413 British thermal units per hour per watt of power consumed, it is evident that there is some relation between lighting and room temperatures. Tons of air conditioning = Btu per hour/12,000. However, the sensation of human comfort, which is not of necessity directly related to room temperature, is the important factor in air-conditioning, rather than the absolute room temperature.

A light source operated in an interior adds two types of heat, usually termed *sensible* and *radiant* heat. Sensible heat is that which is added directly to the air through conduction or convection. It results in a rise in the indicated room temperature. Radiant heat is that added through radiation. Radiant heat is turned into sensible heat only by interception (as by opaque objects such as furniture and the human body, or by air to a very minor degree).

Light sources emit invisible as well as visible radiant energy. Wavelengths between 0.34 micron (the lower limit of ordinary window-glass transmission) and 3 microns are absorbed or reflected to a varying degree throughout this range by the human skin; wavelengths above 3 microns are almost entirely absorbed. A large percentage of incident energy in wavelengths greater than 4 microns is absorbed by window glass.

The relative proportions of sensible and radiant heat are not the same for all light sources, nor does the efficiency of a lamp bear any direct relation to such values. For example, a sodium lamp may have a rated output of 50 lumens per watt, as may a fluorescent lamp. The former, nevertheless, emits slightly more heat per watt because its efficiency is a result of spectral energy concentration near the wavelength of maximum luminosity. A smaller proportion of the total power input goes into the visible sodium line than goes into the continuous visible spectrum of a 50-lumen-per-watt fluorescent lamp, and a larger proportion therefore is converted into heat.

A fluorescent lamp with the same approximate color temperature as an incandescent lamp is more efficient and "cooler" to the touch. The important fact is that a lower total wattage load is needed to produce a

desired illumination level with fluorescent lamps than with incandescent lamps. The ratio of radiant to sensible heat for fluorescent lamps therefore is less than that for incandescent lamps providing the same illumination level. (See Fig. 6–31, page 6–37.)

Certain relationships between heat and the human reaction to it must be understood in order to appreciate the relationship of light to air-conditioning, or of room comfort to temperature and humidity. Table 10–4 indicates the temperature rise resulting, under certain conditions, from various lighting loads in a small office. Temperature rise in a room is a result of many things: primarily heat transfer through walls, heat transfer with air changes, heat radiation that accompanies sunlight, heat emitted by human occupants, and the heat of the occupational process. Artificial illumination, sunshine, and process heat are the most noticeable heat sources. In many offices and stores direct sunlight is eliminated and there is no obvious process heat. It is believed more attention than is justified is directed to the electrical illumination. Today 10 watts per square foot is higher than the average lighting load, and about 3 degrees Fahrenheit is the minimum effective-temperature-difference perceptible to the average human, other conditions being constant.

Humidity. Temperature is measured by a thermometer which, if not otherwise specified, is of the dry-bulb type. However, since the human body regulates its temperature to retain the normal 98.6 degrees Fahrenheit by skin evaporation as well as by radiation and convection, and since the rate of such evaporation depends on the humidity of the air and continues from the normal, active human being, regardless of outside conditions, the sensation of heat as interpreted by human comfort is a function of air water content as well as of absolute temperature. Air (and in fact, any gas) has the property of sharing space with water vapor up to a specific amount. For any given temperature, this amount of water per unit volume is called the saturation point; the related temperature is called the dew point. For example, at 70 degrees Fahrenheit and at sea-level pressure (29.921 inches of mercury) air will hold 0.01865 ounce of water per cubic foot. The variation below this theoretical ideal, which is rated 100 per cent, is called *relative humidity.* With reference to the average human skin, values over 90 per cent are called extreme, those between 60 and 90 per cent humid, between 40 and 60 normal, and under 40 per cent dry. Such generalizations are approximate only, since ambient temperature, activity of the individual, air movement, and so forth make appreciable differences in the apparent sensation which is experienced.

Relative humidity is measured by comparison between wet-bulb and dry-bulb thermometers. The wet-bulb type has its bulb area covered by a wet cloth. In use, air movement past the wet bulb is required to encourage evaporation. Evaporation tends to lower the reading below that recorded by a dry-bulb instrument. The relation between the two temperatures is a measure of relative humidity. If the wet-bulb thermometer shows the same temperature as the dry-, it indicates that no water has evaporated and therefore that the humidity is 100 per cent.

Table 10-4. Temperature Rise Over a 7-Hour Period Attributed to the Electrical-Lighting System in a Two-Window Office (300-Square-Feet Floor Area)*

ELECTRIC POWER DELIVERED TO LIGHTING SYSTEM (watts per sq ft)	TEMPERATURE RISE (degrees fahrenheit)†	
	Windows and Transom Open	All Openings Closed
2	0.5	1.5
4	1	3
6	1.25	4.5
8	1.8	6
10	2.25	7.5
12	2.6	9
14	3.1	10.5
16	3.5	12
18	4	13.5
20	4.3	15

*Sharp, H. M., "Lighting and Air Conditioning," *Lighting and Lamps*, April 1946.
†The test-room temperature rise shown here has been corrected by comparison with data on the "control" room without electric lighting so that the influence of inside and outside temperatures and wall materials is minimized.

Comfort limits. The relationship between comfort and temperature and humidity has been determined by a study based on human experiences and voiced reactions. A summary of such observations is compiled in Fig. 10–24. The chart indicates that the *effective* temperature is a few degrees below the dry-bulb temperature, the amount below being indicative of the dryness of the air. It shows also that a person does not on the average notice changes of humidity or temperature when their net result is a change in effective temperature under 3 degrees Fahrenheit. The figure varies to some extent with absolute values, climate adaptation, occupational activity, and individual human sensitivity.

The data of Fig. 10–24 apply to still-air conditions with which are associated the highest effective temperatures. Air movement increases water evaporation from the skin and reduces the effective temperature.

Lighting load on an air-conditioning system. An important point in the design of an air-conditioning system is that increasing the lighting level by doubling the watts per square foot is not likely to result in the requirement of a refrigerating unit of doubled capacity. Table 10–5 indicates that from 9 to 24 per cent of the air-conditioning load for a variety of interiors may be attributed to lighting.

By raising skin temperature above the comfort zone, radiant heat in some cases may cause discomfort when the air-temperature-humidity relationship is within the zone (Fig. 10–24). In other cases, when the air-temperature-humidity relationship is below the comfort zone, radiant heat may provide comfort by raising the skin temperature into the zone.

The rate of heat loss by radiation depends on the exposed surface of the body and upon the difference between the mean surface temperature of the surrounding walls or other objects, called *mean radiant temperature* (mrt).*

Heating, Ventilating, Air Conditioning Guide, 1947, American Society of Heating and Ventilating Engineers, New York.

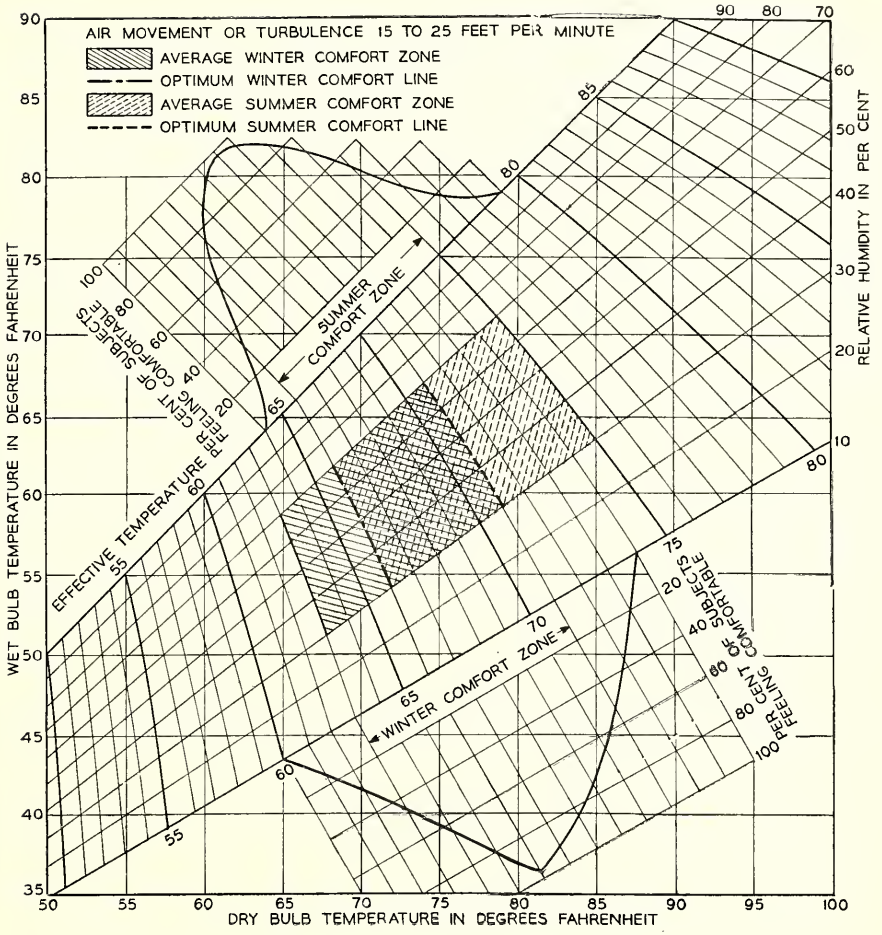


FIG. 10-24. Still-air comfort chart of the American Society of Heating and Ventilating Engineers.*

Note: Summer and winter comfort zones apply to inhabitants of the United States only. Application of the winter comfort line is further limited to rooms warmed by central-heating systems of the convection type. The line does not apply to rooms heated by radiant methods. Application of the summer comfort line is limited to homes, offices, and the like where the occupants become fully adapted to the artificial-air conditions. The line does not apply to theaters, department stores, and the like where the exposure is less than 3 hours. The optimum summer comfort line shown pertains to Pittsburgh and to other cities in the northern portion of the United States and southern Canada, and at elevations not in excess of 1,000 feet above sea level. An increase of approximately 1 degree effective temperature should be made per 5-degree reduction in north latitude.

* *Heating, Ventilating, Air Conditioning Guide,* 1947, American Society of Heating and Ventilating Engineers, New York.

Available data indicating the effect on comfort of mean radiant temperature is less conclusive than that available on effective temperature, but it is accepted that a change of 6 degrees in mean radiant temperature is the *minimum significant perceptible difference*. The problem is complicated by the distinct differences in sensitivity of different parts of the body. The backs of the hands and the face are the most sensitive parts. (See Table 10-6.)

Thus, under certain conditions, local lighting installations may be the cause of some radiant-heat discomfort despite a comfortable air-temperature-humidity relationship. Since the heat removed from the skin by air convection or conduction may not equal that added by a concentrating reflector, a local temperature rise may result. Hot ceilings, walls, or floors may be the cause of a similar phenomemon.

Table 10-5. Relative Values of Various Contributing Loads Given in Per Cent of Total Cooling Load*

CONTRIBUTING LOAD	PER CENT OF TOTAL COOLING LOAD						
	Offices	Apparel Stores	Department Stores	Drug Stores	Beauty Shops	Restaurants	Small Shops
Lighting	17	24	24	12	9	9	19
Solar radiation through windows	16	6	7	0	3	2	4
Conducted heat	17	26	15	23	26	12	28
Occupants	14	18	20	32	15	26	14
Outside air	26	22	28	23	15	29	25
Miscellaneous	10	4	6	10	33	22	8

*Sharp, H. M., "Lighting and Air Conditioning," *Lighting and Lamps*, February 1946.

Table 10-6. Relationship Among Mean Radiant Temperature (MRT), Flux Distribution Characteristics of Luminaires, Power Load, and Illumination Level in Various Interiors*

AREA	LUMINAIRE	LAMP	WATTS (sq ft)	MAX HORIZONTAL FOOT CANDLES	MRT AT POINT OF MAX FOOT CANDLES	MRT PER FOOT CANDLE	MRT OF TOTAL INTERIOR
Private office	Indirect	Incandescent	4.5	24	1.4°	0.06	0.8°
Private office	Direct-indirect	Incandescent	3.5	60	0.25	.004	0.8
General office	Indirect	Incandescent	8.3	33	2.0	.06	2.0
General office	Luminous indirect	Incandescent	5.0	40	3.0	.07	4.0
General office	Luminous indirect	Incandescent	3.0	18	1.0	.055	1.0
Drafting room	Indirect	Silver bowl incand.	5.0	30	3.0	.1	3.0
Retail store	Indirect	Incandescent	4.5	10	1.0	.1	1.0
Dept. store	Indirect	Incandescent	2.6	15	1.0	.06	1.5
Variety store	Indirect	Incandescent	6.25	42	1.5	.04	1.8
Variety store	General diffuse	Incandescent	3.3	39	3.5	.09	6.5
Industrial plant	Direct	Silver bowl incand.	4.3	39	1.5	.04	1.0
Industrial plant	Direct	Incandescent and merc. vapor	2.65	64	2.8	.044	2.0
Local lighting	Direct	Incandescent	—	.25	0.006	—	—

*Sharp, H. M., "Lighting and Air Conditioning," *Lighting and Lamps*, June 1946.

RESIDENCE LIGHTING

The rooms of a home are expressions of the method of living, taste, activities, and so on of a family or an individual. Residential-lighting design is a compromise between individual taste, tradition, decoration, and practical engineering. The recommendations presented here have been selected and condensed from the I.E.S. *Recommended Practice of Home Lighting*.

The lighting of living room, dining room, and kitchen in farm homes may differ from that of similar areas in urban residences because the occupancy may be somewhat different. In general, however, residential space is utilized today in urban and rural areas for about the same purposes. Farm buildings which may or may not be directly connected with the farmhouse require good illumination also. (See the following section.)

Fundamentals of Residence Lighting

Despite the fact that distribution curves, symmetrical spacings, luminaire efficiencies, and similar data at present are not always considered essential in residence-lighting design, the basic factors of quantity and quality of illumination still should be considered both in the design of home-lighting equipment and in its application. As in any other interior, lighting should be planned objectively to simplify seeing tasks, and subjectively to increase human comfort. Similarly, it should be so co-ordinated with the architectural detail and interior decoration as to blend inconspicuously with it and to add interest to it. Stated in direct reference to the home, the broad lighting considerations that should be used as a guide are:

1. The attainment of the recommended illumination levels for the many visual tasks common to the home.
2. The provision of a quality of illumination that ensures seeing comfort for the occupants.
3. An understanding handling of the color of the light sources utilized.

Quantity of illumination. Varied seeing tasks in the home require different quantities of illumination and brightness ratios. Recommended illumination levels are included in Table 10–7. Typical luminaires are shown in Figs. 10–25 to 10–31.

Quality of illumination. To ensure comfort in the use of the recommended illumination on seeing tasks, it is essential that the resultant task brightness not greatly exceed that of the background against which it is viewed. This requires such a distribution of the light within a room that the room is free from glaring bright spots and deep shadows. Glare too often is associated only with unshaded lamps. Luminaires may be sources of discomfort also if they are much brighter than the surface against which they are viewed. Usually, comfortable, low-brightness ratios may be attained by distributing light uniformly throughout a room. Low-brightness luminaires are particularly important in living rooms, dining rooms, and bedrooms. In these rooms persons often spend many hours in

seated positions, which may bring the luminaire within their view. It is not suggested that a room used for social conversation or other "nonseeing" activity be illuminated to eliminate all shadow and contrast. Such a room would be unattractive. However, deep shadows may cause unnecessary eyestrain and fatigue when the room is used for difficult seeing tasks, rather than for relaxation and conversation.

Relationship between ceiling, wall, and floor color and reflectance, and light utilization and appearance. The utilization of light within a room depends on the wall, floor, and ceiling reflectances. A room is likely to appear attractive to most people when the ceiling has the highest, the floor the lowest, and the wall an intermediate reflectance. The following reflectances are typical of good practice today: ceilings between 65 and 80 per cent; floors between 10 and 20 per cent; and walls between 35 and 55 per cent. In rooms where visual tasks are difficult the higher values are better. Wide variations from these values often are used in rooms where decorative treatment is of paramount interest and severe visual tasks are not performed.

Table 10-7. Recommended Illumination Levels for the Home*

AREA AND VISUAL TASK	FOOTCANDLES MAINTAINED IN SERVICE
GENERAL LIGHTING FOR:	
Entrance hall, stairways, and stair landings	5
Living room, library, sunroom	5
Dining room	5
Kitchen	10
Bedroom	5
Bathroom	5
LIGHTING FOR:	
Kitchen (work counter, range, and sink)	40
Dressing-table mirror†	20
Bathroom mirror†	40
Laundry (ironer, ironing board, or tubs)	40
Work bench	40
Reading	
Prolonged periods (smaller type)	40
Casual periods (larger type)	20
Sewing	
On dark goods, fine needlework	100
Average sewing (prolonged)	40
Average sewing (periodic)	20
Writing	20
Children's study table‡	40
Game tables	
Card table	10
Ping-pong	40

*The values given for general lighting are intended to minimize brightness ratios between the illuminated visual tasks and the surround. Where difficult seeing tasks are not involved, the values listed aim to assure safe passage, eye comfort, and charm.

The given values for typical home tasks are chosen for persons with normal vision, giving proper consideration to such matters as cost and practical attainment. They do not represent the optimum, since under some conditions more light may be necessary and desirable, and often more light is attainable.

The values listed may be attained by either fixed or portable luminaires, or by a combination of the two.

†To be delivered on both sides of the face.

‡Often a dining-room table.

The appearance of an object is influenced by the color of the incident light. For example, the monochromatic yellow color of light from the sodium lamp is not suited to home lighting because, when they are illuminated by this light, all objects which do not have some yellow in their surface appear black, and the yellow in others is so emphasized as to distort completely the intended appearance. Because most homes are at least partially illuminated by direct sunlight and skylight during the day, interior colors often are selected for their outdoor appearance. A daily variation in appearance is caused by hourly changes in the orientation of the sun, by weather variations, and by the spectacular sunrise and sunset hues. Also, since the color of light from electric lamps is uniform and does not exactly duplicate either sunlight or skylight, another variation is introduced. Generally speaking, of the light sources used in homes the 300-watt incandescent lamp is the one which produces light most similar to direct sunlight. Light from daylight fluorescent lamps is most similar to that from a clear blue sky; and light from white fluorescent lamps is somewhat similar to sunlight and skylight combined.

By comparison, light from incandescent lamps emphasizes red and yellow colors and tones down the greens and blues; light from fluorescent lamps emphasizes green and blue colors and tones down the reds and yellows. (See Section 4.) With either type of lamp, high chromas in the light-controlling materials of luminaires or on large wall areas should be avoided if it is desired to retain an outdoor appearance.

It should be realized that in a store the appearance of household accessories is influenced in a similar manner by the illumination and decoration. A considerable change in appearance may be noted if the home conditions under which the accessory is to be used or displayed differ in appearance from those of the store.

The usual lighting requirements of each major room of the average home are discussed on the following pages. The recommended luminaire light distribution characteristics should be adhered to. However, decorative detail is a matter of taste and market supply.

Entrances, Halls, and Closets

Architectural treatment dictates the placement and type of entrance luminaires. Brackets that provide downlight on steps (Fig. 10–25a) preferably are placed at each side of the door. Often a single bracket above the door harmonizes better with the architectural design but may prevent seeing clearly the face of the caller. On an attached porch, a suspended lantern (Fig. 10–25c) should be placed on the porch ceiling so that the steps are lighted for safety. Clear glass panels in brackets or in a lantern should be avoided, since lighted lamps behind clear glass may prove more blinding than helpful. When a doorway is slightly recessed, a recessed element (60- or 100-watt lamp) may be inset inconspicuously in the soffit above, with a pleasing result. Use of a 150-watt projector floodlamp (Fig. 10–25g) or a 100-watt lamp in an angle reflector set under the eaves

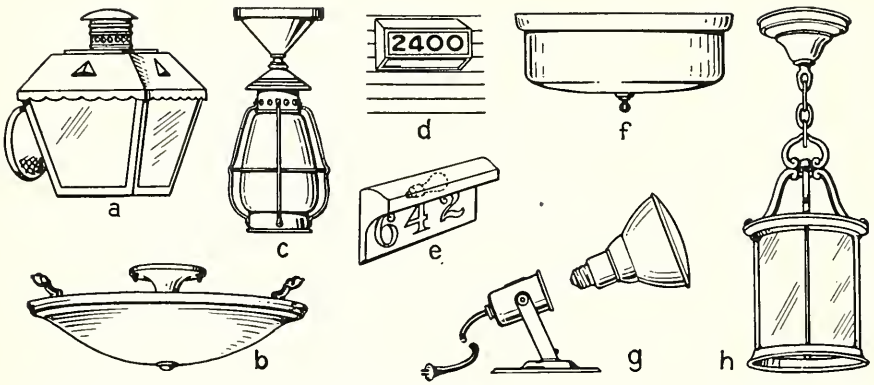


FIG. 10-25. Typical recommended luminaires for entrances, halls, and closets. a. Lantern bracket. b. Semi-indirect. c. Ceiling lantern. d. Recessed house number. e. Attached house number. f. Semidirect. g. Projector lampholder. h. General diffuse lantern.

and switch-controlled from the house, will provide ample protective lighting between the garage and the house as well as yard and garden lighting.

A lighted house number may be incorporated in the entrance lantern, in a separate recessed box (Fig. 10–25d) located in the house wall or steps, or in a special applied box connected to the door-bell circuit (Fig. 10–25e). The size of numerals is important; for clear visibility up to 75 feet, they must be at least 3 inches high with a half-inch stroke.

In halls with open stairways, lantern-type luminaires (Fig. 10–25h) often are used. Their scale and design should fit the interior. They should be placed to illuminate adequately for safety on the stairs. The type shown in Fig. 10–25b must be mounted close to the ceiling in order to shield the lamps from the view of persons descending stairs. In smaller halls the type shown in Fig. 10–25f may be used, and for vestibules and narrow passages the same type in a size as small as 6 inches in diameter for a 40-watt incandescent lamp may be adequate.

Light is essential in a closet unless it has less than 9 square feet floor area or is not more than 18 inches in depth, or where the light spilled from an adjacent room is sufficient. When closets are located in hallways it is often practical to place the hall fixture in front of the closet door. A simple porcelain pull-chain socket mounted just over the door frame on the opening side serves shallow closets. Deeper closets are better served by a small fixture, such as shown in Fig. 10–25f, mounted on the closet ceiling, controlled by a manual switch just inside the door or by an automatic door switch. A lamp rating of 60 watts is recommended as the minimum.

Living Rooms

In living-room lighting a degree of flexibility is desirable to meet varied requirements. This is provided by:

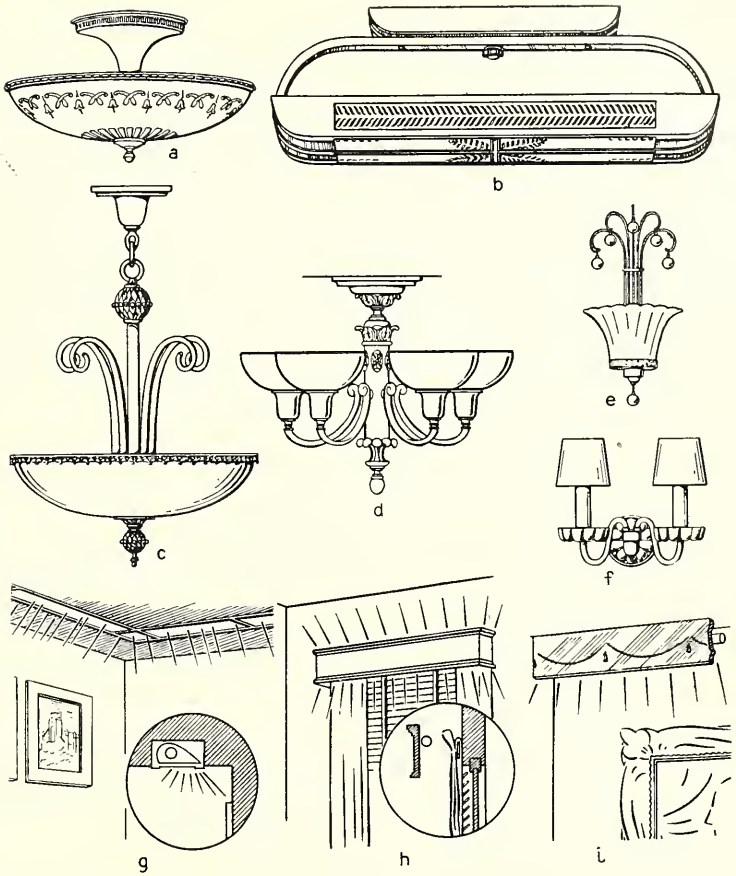


FIG. 10-26. Typical recommended living-room luminaires. a. Semi-indirect, ceiling-mounted (for incandescent-filament lamps). b. Semi-indirect, ceiling-mounted (for fluorescent lamps). c. Semi-indirect, suspended. d. Semi-indirect, multiple-arm. e. Wall urn. f. Decorative wall bracket. g. Recessed element. h. Window cornice. i. Side-wall valance.

Ceiling fixtures. A ceiling center fixture similar to the types shown in Fig. 10–26 provides for the modest home (1) soft background lighting for more visually comfortable use of portable lamps, (2) lighting for game tables in center of the room without need to move portables, (3) convenient over-all room light upon entering, and (4) flexibility in the room's atmosphere for varying occasions. The recommended types distribute light to the ceiling and side walls and diffuse light throughout the room. The recommended minimums (14-inch diameter and 150-watt lamp) for the types shown in Figs. 10–26a and c will be adequate for rooms of 150 to 200 square feet or less. Large luminaires close to the ceiling are less consipcuous than small low mounted ones. Generally, they should be mounted not less than 7 feet 6 inches above the floor. In small rooms with ceilings over 9 feet high, suspended types such as shown in Figs. 10–26c and d often are used.

Wall brackets and urns. Wall brackets and urns of either the purely decorative or functional type have living-room applications. The wall urn illustrated in Fig. 10–26e when used in pairs on opposite walls increases the general illumination of a room, especially in low-ceiling rooms and when located on the end walls of a long narrow room in which a centrally located luminaire lights side walls better than end walls. The type shown in Fig. 10-26f is better suited to purely decorative highlighting. In rooms of normal ceiling height they are mounted 5 feet 6 inches above the floor and should be arranged as part of a permanent furniture grouping.

Built-in luminous elements. When cost is not a limiting factor, skillfully applied and balanced luminous elements (Figs. 10–26g, h, and i) offer endless possibilities and may replace the center fixture or augment it. The simplest methods are shown. An indirect, or luminous cove, continuous or sectional, is not recommended for other than its decorative effect unless it can be mounted at least 1 foot from the ceiling. Greater separation and the use of directional reflectors is desirable.

Table and floor lamps. To ensure desirable illumination levels for sewing, reading, and other seeing tasks, portable luminaires should be placed not more than 30 inches from the work unless a high level of general illumination also is provided. Portable luminaires prove the most flexible means of obtaining light at desks, davenports, reading and sewing chairs, and pianos. (See Fig. 10–27.) Portable-lamp lighting proves more comfortable and less spotty when wall and floor brightnesses are sufficient to minimize contrasts between the seeing task and the surround.

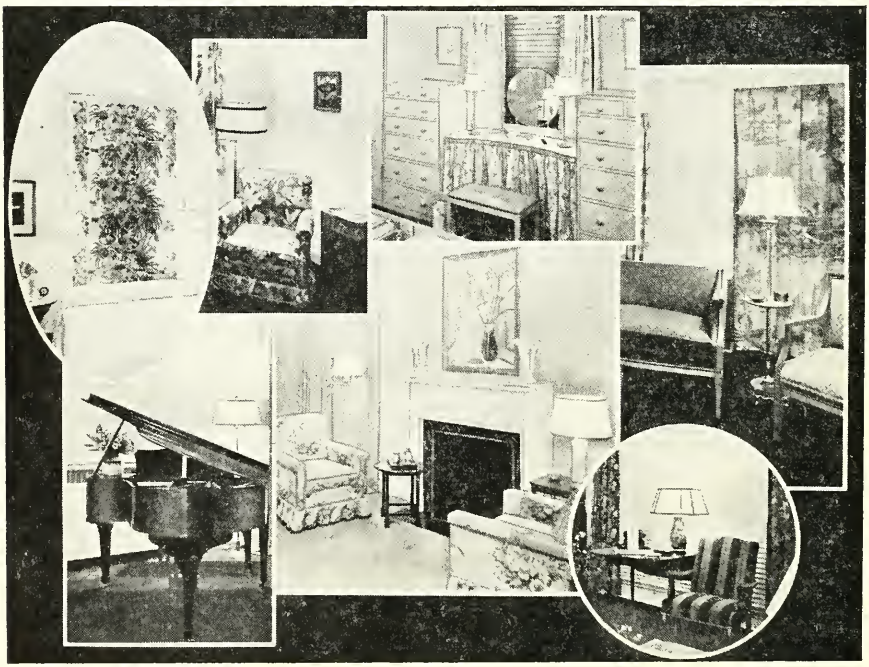


FIG. 10-27. Typical wall, table, and floor lamps selected and placed for decorative harmony and to provide the recommended quantity and quality of illumination.

Dining Rooms

Whether the dining table is in a room of its own or is at one end of the living room or kitchen, it is the center of interest for that area. Linen, china, and polished silver can gleam only if the illumination is provided by large-area luminaires of proper brightness. The lighting method and the choice of luminaires, however, depend to a great degree on the activities at the dining-room table. If it serves as a dining area only, individual taste and a desire for sparkle may dictate. When the dining table is used also for sewing, studying, writing, or games, the recommended illumination for these tasks should be provided. The dining area, therefore, requires flexible lighting. It can be provided by a choice or combination of ceiling luminaire, brackets, and built-in lighting. (See Fig. 10–28.)



FIG. 10-28. Typical recommended dining-room luminaires. a. Semi-indirect, with downlight. b. Semi-indirect, with inner diffusing bowl. c. Semi-indirect, multiple-arm. d. Shaded candles. e. Semi-indirect, for fluorescent lamps. f. Semi-indirect, ceiling mounted. g. Direct, spotlight or downlight. h. Over-cabinet lamp. i. Cove.

Ceiling fixtures. When a luminaire is suspended over the table it becomes part of the table grouping and usually is mounted with the bottom of the fixture 30 to 36 inches above the table top. The types shown in Figs. 10–28a and d are designed so that a portion of the light emitted is directed downward to increase the brightness of the table and create sparkle by reflections from the silver, china, and crystal. When the dining table becomes a utility table after dinner, a luminaire should be chosen that produces lighting with the downward light diffused by means of a glass or plastic reflector, such as used in the type shown in Fig. 10–28b.

When it is desired to mount a luminaire close to the ceiling rather than to suspend it, the types shown in Figs. 10–28e and f are recommended. The types shown in Figs. 10–28a and c may be installed without suspension. Close-to-ceiling luminaires, unless designed with a downlight component, will not highlight the table as the suspended type will.

Wall brackets. Wall brackets add a pleasing note of decoration in the dining room and increase wall brightness. They usually are mounted 5 feet 6 inches above the floor and should be used in pairs. They should be used in conjunction with a ceiling-mounted luminaire. Because of the remote location of wall brackets they alone cannot place dramatic emphasis on the table service.

Built-in lighting. The dining room is adaptable to decorative lighting from window or wall valances, coves at opposite sides of the room, and recessed spots and lights in and above china cabinets. Coves and valances may provide general illumination. Valance and cornice lighting is applicable to the dining room also. Lamps may be installed on the top of high china cabinets to give additional background lighting as well as to be decorative. Downlights similar to that shown in Fig. 10–28g give dramatic emphasis to the table only. When downlights are installed over the table, additional luminaires, wall brackets, torcheres, urns, valances, or coves are necessary to reduce contrast and provide background lighting.

Kitchen, Laundry, and Garage

Illumination design for kitchens should provide (1) light distributed generally about the room, and (2) light specifically directed on work areas: sink, range, counters, and dining table, for example. Luminaires similar to those shown in Figs. 10–29a, b, and c will provide general illumination. Indirect luminaires should be mounted so as to permit a wide distribution of light. The bright lamp neck should be shielded from the field of view. General illumination alone will not prevent the annoyance and inconvenience of working in shadow at the sink, range, or other work area. The type of luminaire installed over the sink depends upon window and cabinet treatment. A small duplicate of the central luminaire often is used. Luminaires such as those in Figs. 10–29a and c with a 100-watt or a 40-watt lamp also may be used over the sink. Downlights similar to that

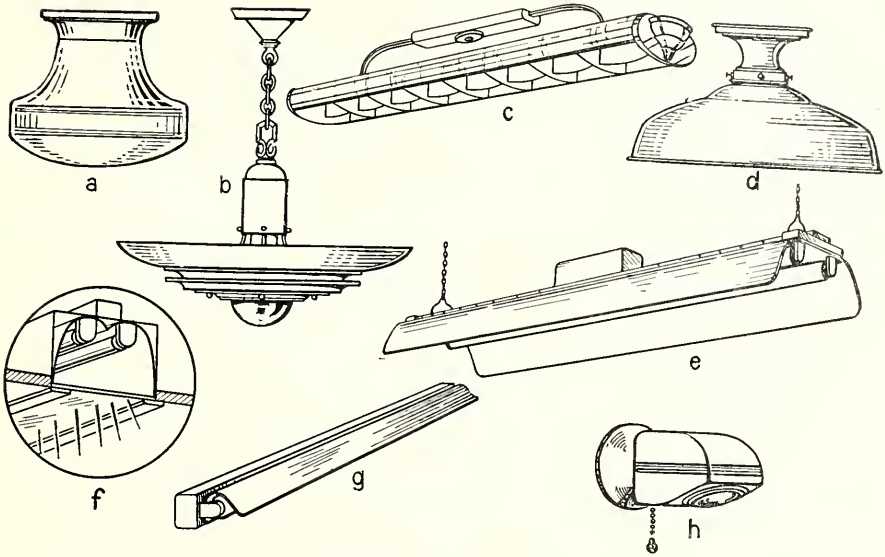


FIG. 10-29. Typical recommended luminaires for kitchen, laundry, and garage. a. General diffuse enclosing globe. b. Indirect. c. Semidirect, louvered, for fluorescent lamps. d. Direct, for incandescent-filament lamps. e. Direct, for fluorescent lamps. f. Recessed element. g. Wall bracket, for fluorescent lamps. h. Wall bracket, for incandescent lamps.

shown in Fig. 10–29f may be recessed in a ceiling or in a furred-down section between cabinets over a sink. Opal-glass plates should be used with incandescent lamps, stippled or etched glass plates or louvers with fluorescent lamps. Where sinks stand against unbroken wall surfaces or beneath double-sash windows, a bracket similar to that shown in Fig. 10–29g in the former case, or 10–29h in the latter, often is attached to the wall or to the center connecting window frame. Bracket types such as shown in Figs. 10–29g and h are suitable also for use over ranges and work counters. They should be mounted approximately 56 to 58 inches above the floor for greatest visual comfort.

When lights are not built into cabinets to illuminate the counter surface, brackets similar to Fig. 10–29g should be installed on the wall under the cabinets.

Illumination designs for laundries should provide light on work areas such as wash tubs, ironing board, ironer, and counters or sorting table. A single ceiling luminaire cannot properly light all of these areas. A minimum of two is recommended. Luminaires similar to those in Figs. 10–29a, d, and e are recommended over laundry work areas and basement work benches.

In the garage two luminaires of the type shown in Fig. 10–29d are recommended.

Bedrooms

Bedrooms in the home are used for dressing, applying make-up, reading, sewing, and studying as well as for sleeping. A ceiling luminaire is recommended for every bedroom. The types in Figs. 10–30a, b, and g are similar in performance, and the choice between them depends on individual preference. The type shown in Fig. 10–30d may be preferable for children's rooms, since it has very low brightness when viewed from reclining positions. The recommended minimums (14-inch diameter and 150–watt silvered-bowl lamp) are adequate only for small- and medium-sized rooms.

For built-in dressing tables between wardrobes, excellent illumination for make-up is provided by a recessed luminous element in a furred-down ceiling. (See Fig. 10–30h.) Thin etched glass is recommended for fluorescent lamp elements and diffusing opal for incandescent lamp designs. The dresser top should be mirrored to reflect light under the chin.

Luminous panels on each side of the mirror are excellent when inset in the wall as in Fig. 10–30f. Lamps with half-cylinder shades (Fig. 10–30c) may be mounted on the mirror. A bracket with an open-bottom oval shade placed over the door mirror is inexpensive.

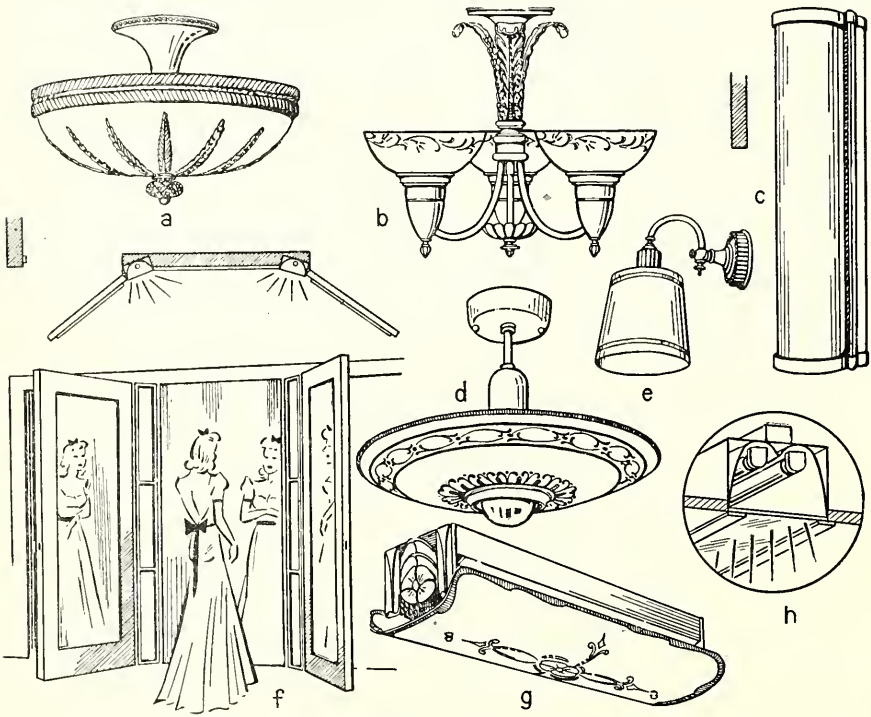


FIG. 10-30. Typical recommended bedroom luminaires. a. Semi-indirect, for incandescent-filament lamps. b. Semi-indirect, multiple-arm. c. Bracket (fluorescent lamp). d. Indirect. e. Bracket for door mirrors. f. Recessed elements for illumination at a mirror. g. Semi-indirect, for fluorescent lamps. h. Recessed fluorescent element, use over vanity.

Wherever fixed luminaires are not installed, portables are needed. Wall-mounted luminaires over the bed and tall bed-side table luminaires will provide illumination for reading. Portables at the dresser, desk, reading, or sewing chair are recommended. A small 6-watt night lamp plugged into a low convenience outlet is desirable, especially in nurseries.

Bathrooms

The most important illumination in the bathroom is that at the mirror. The face of the person in front of the mirror, not the mirror, should be illuminated. The ideal method is to provide a luminous area around the entire mirror circumference. Two brackets, one at each side of the mirror, mounted approximately 5 feet 6 inches above the floor, also provide good coverage. Either incandescent or fluorescent lamps may be used as in Figs. 10–31e and g. The length of the fluorescent tube distributes more light over the face and neck. Where the budget permits only one lighting outlet in the bathroom, a shaded-lamp over-mirror luminaire can be used. lamps are shaded.

Unless a bathroom is less than 60 square feet in area, it should have a ceiling luminaire. If a small budget necessitates a choice between a ceiling luminaire and mirror illumination, the room should be illuminated from the mirror area. A wall switch inside the bathroom door should be used to control all luminaires.

Enclosed showers should have a vapor-proof ceiling luminaire such as that shown in Fig. 10–31d, controlled by a switch outside the compartment. In large bathrooms a recessed element over the tub also is a convenience. It should be switch controlled at the door.

For safety and convenience, a night light in the switch plate at the door or one in the baseboard is recommended.

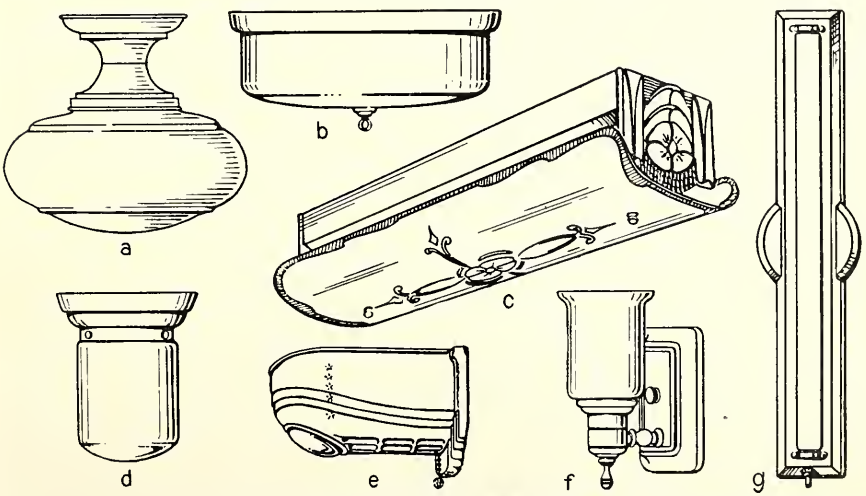


FIG. 10-31. Typical recommended bathroom luminaires. a. General diffuse enclosing globe. b. Semidirect, ceiling-mounted, for incandescent-filament lamps. c. Semidirect, ceiling-mounted, for fluorescent lamps. d. Vapor-proof, for shower. e. Semi-indirect, bracket with lens. f. Semi-indirect, bracket. g. Wall bracket.

Floor, Table, and Wall Lamps

It is possible, through skillfully planned built-in forms combining efficient fluorescent and spotlight sources, to develop satisfactory lighting throughout a home without the use of portable lamps. Such a plan requires relatively fixed positions for furniture, and its cost at present makes it impractical for the average home. Most homemakers still prefer the flexibility and decorative character of portable lamps. Fixed ceiling luminaires do not produce the illumination levels recommended for difficult seeing tasks at furniture groupings. Therefore, portables are recommended.

Each portable, be it a table, floor, or wall type, should harmonize in scale, material, and form with its room environment and produce the level of illumination recommended in Table 10–7 for the seeing task associated with the specific grouping for which it is selected. (See Fig. 10–27.) Table 10–8 gives the range of wattage ratings of incandescent and fluorescent lamps required to meet these footcandle recommendations. Table 10–8 also gives efficient lamp heights and shade diameters for the desired distribution.

Inner diffusing bowls. The I.E.S. certified lamps of 1933–1941 had diffusing bowls within the shades. The purpose of diffusing bowls is to improve the quality of lighting for the more exacting seeing tasks, to reduce the brightness of incandescent-lamp filaments rated 100 watts and greater, to soften shadows, and to minimize reflected glare. This improvement in quality is gained with some loss in luminaire efficiency.

Table 10-8. Recommended Characteristics of Portable Luminaires for Use in the Home

	TOTAL LAMP WATTS		HEIGHT OVER-ALL (inches)	SHADE DIAMETER, LOWER EDGE (inches)
	Incandescent	Fluorescent*		
Lamps for flat-top desks and tables	100–150	30–40	19–28†	14–18
Vanity lamps for:				
Dressing tables	75–100	15–20‡	20	8–10†
Dressers	75–100	15–20	26	8–10†
Wall lamps	75–100 100–150	15–40‡	50–60 above floor	8–10§ 12–18‖
Floor lamps	150–500	¶	50–58**††	16–20‡‡

*Lamp watts only. Does not include power consumed by auxiliary and refers to straight tubes only.

†Some models using fluorescent lamps may be shorter, since the long form and moderate brightness allow a lower position within the shade, with a wider resultant spread of light.

‡In vanity and wall lamps utilizing straight fluorescent tubes full-length shielding is required.

§This size is appropriate only with 75-watt, incandescent-filament lamps (without diffusing bowls) over sinks and both sides of a dressing-table mirror.

‖This size (with bowls) required for critical seeing tasks, for use over beds desks, sewing machines, chairs, etc.

¶Circular fluorescent lamps (32-watt) are being used as supplementary sources.

**An adjustable feature is most desirable in floor lamps in order to fit the height to the varying seating heights of lounge chairs and davenports.

††Totally or semi-indirect torchères should be 60 to 66 inches high.

‡‡The shades on small-scale bridge lamps may be smaller (10 to 14 inches), since the extension arm brings the source closer to the user.

Shape, size, and density of bowl are important. For noncritical seeing tasks, table lamps 19 to 24 inches high equipped with two adjustable sockets for 60-watt incandescent lamps are satisfactory. Inner bowls should not be used in dressing-table lamps.

Shades for portable luminaires. Shade linings should be white, ivory, or a very pale tint. Slant-sided shades aid in spreading light over a wider area. Shades for floor and table types which utilize fluorescent lamps can be reduced in depth, and may therefore have desirable large lower diameters without appearing too heavy and out of proportion in a small room. Open-top shades produce interesting highlights on pictures and walls and provide a more uniform distribution of light. A disk of shallow louvers or of silk or plastic attached to the upper ring is often necessary to shield the lamp's "mechanics" from the view of standing observers. The transmittance and reflectance of shade materials should be balanced with the brightness of the lamps used so that the luminaire will blend with the surround brightness.

Placement of portable luminaires. All portables should be placed close to whatever is to be seen. Most of those centered on a large table serve only for decoration. The type (floor, table, or wall) selected for a given grouping should be the one which brings the light source nearest the user. Swivel and extension arms are advantageous, especially at large desks, sewing tables, and broad-armed chairs.

Luminaires used for sewing, writing, or other handwork should be placed on the side opposite the hand used so that the hand will not cast its shadow over the work. Shadows are minimized by diffusing bowls or fluorescent lamps and when a fixed ceiling luminaire is used in conjunction with the portables.

Floor lamps usually should be placed toward the rear of the chair or davenport for which they are selected, so that a seated person does not view the under part of the shade. Luminaires should not be placed directly in front or behind a person. Secretary and other tilt-top desks require a floor type—either the small-scale bridge or larger swivel types, depending on the desk size.

Davenports placed flat against a wall with no tables to accomodate portables are served best by floor types of the shorter dimensions given. Swivel-arm, floor-type portables serve spinet and miniature pianos, though a taller floor type placed close to the keyboard is better for upright or grand pianos.

Dressing-table luminaires should be placed about 30 inches apart. Shades should be near white and at face height. Wall luminaires mounted over beds should be not more than 26 inches above the mattress top.

Torcheres do not give sufficient downlighting for critical seeing. They serve best for soft background lighting, especially in halls, dining rooms, and game rooms.

A balanced arrangement of luminaires within a room usually is pleasing.

FARM LIGHTING

Farm Exteriors

Though it may be used less frequently than other entrances, the front door of the farm home should be lighted as it may be the guest entrance. The rear or side entrance is used regularly and often leads directly to an auxiliary farm building. A high level of illumination is recommended at doors. Individual reflectors, projector-type lamps, or floodlights provide suitable coverage for the large open areas between and around the buildings fenced off from the rest of the farm land. (See Fig. 10–32a.) Except in midsummer such lighting is needed in the regular work day, either morning or evening or both. Luminaires should be suspended from brackets on the side of the buildings, or on poles. In any event, they should be as high as possible in order to distribute light over a wide area and should be securely installed. Their exact number and location and the lamp used depend on the individual farm and the distances and areas involved. The illumination provided close to the buildings themselves should be sufficient for routine chores. The spaces between may be satisfactorily lighted if dependence on silhouette vision as in street lighting is planned.

Farm Buildings

Two types of incandescent-lamp reflectors are used most frequently for farm buildings—the *standard-dome reflector* and the *shallow-dome reflector*. The standard industrial dome affords a greater protection from glare. The shallow-dome reflector spreads light over a wider area. Other reflectors frequently used are the *angle* type and, for local lighting, the *deep bowl*. In all cases, reflectors should be durable, efficient, and easily cleaned. For this reason, porcelain-enameled steel or aluminum is recommended.

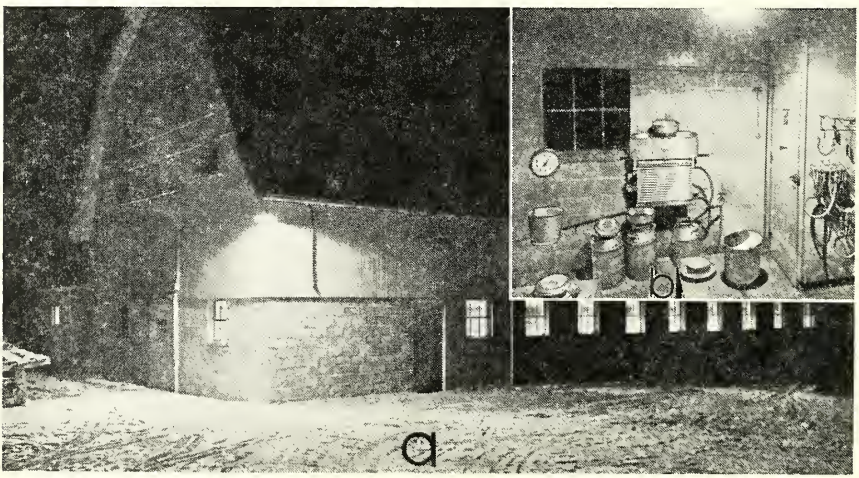


FIG. 10-32. a. Farm-yard lighting. b. Small room in a milk house lighted by a 75-watt lamp in an industrial-type reflector.

Milk House

The milk house requires illumination, since considerable work is performed there during the dark hours following the milking of the cows in the late afternoon and early morning, particularly during the winter months when the days are short. The various operations such as milk separation, cooling, bottling, etc., require maintenance of most sanitary and orderly conditions. Illumination assists in carrying out such a program.

For most rooms, a symmetrical arrangement provides the best light distribution. (See Fig. 10–32b.) Under some conditions, the arrangement of milk-handling equipment calls for local or localized-general lighting. For general lighting, 100- to 150-watt, incandescent-filament lamps should be specified; for localized-general lighting, 60- or 75-watt, incandescent-filament lamps and for local lighting, 25- or 40-watt, incandescent-filament lamps. Direct type, corrosion resistant reflectors or enclosing globes are preferable for general lighting, while deep bowl reflectors are preferable for local lighting. Not less than 5 footcandles and preferably 10 should be provided for general work. Higher levels justified for special operations are being provided in some places by fluorescent-lamp equipment.

Barns

There are many types of barns; the most common are dairy, horse, cattle, sheep, hog, and general barns. Typical barn design seldom provides for much daylight, and much of the regular work in a barn is done during hours when there is little or no daylight available. Good electrical illumination is necessary. The care of the stock, especially the sick and the young, is aided by proper lighting.

The *dairy barn* should have better lighting than most types because of the particular need of cleanliness, an important factor in keeping the bacteria content of milk at a low point. Usually, dairy barns are arranged in a series of alleys, one set for feeding and the other set for milking and cleaning. This lends itself readily to the installation of luminaires spaced 10 to 15 feet apart down the center of each alley. (See Fig. 10–33a.) For the care of young calves box stalls with 4-foot partitions usually are located at one end of the barn. Unless an alley light comes directly opposite, a local light over each stall is desirable. Shallow-dome reflectors using 60- or 100-watt incandescent lamps and mounted close to the ceiling are recommended. If the ceiling is open, the bottom of the reflector should be even with the bottom of the joist. For individual stalls 40- or 60-watt, incandescent-filament lamps are used.

The *cattle barn* is a closed area containing feed troughs. In general, a row of lamps in reflectors over the troughs will provide adequate light at the troughs and over the rest of the barn floor. In large barns, additional outlets are necessary, and, therefore, general lighting for the entire area is recommended. With 12- to 15-foot spacings, the 60-watt lamp is preferred.

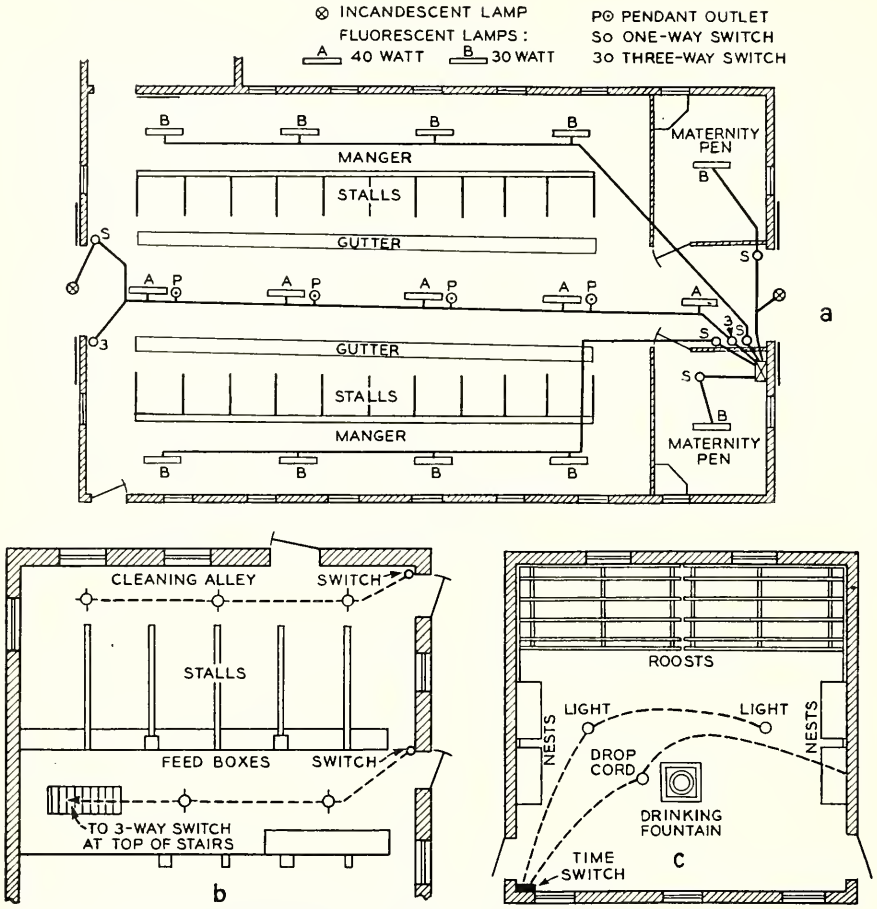


FIG. 10-33. Lighting layouts for various types of farm buildings. a. Gambrel-roof dairy barn. b. Horse barn. c. Poultry laying house.

The *horse barn* normally is arranged in a series of feeding and cleaning alleys, similar to the dairy barn. The lighting layout should be similar to that for the dairy barn. Luminaire spacing in the cleaning alleys should be such that light is distributed into all stalls. (See Fig. 10–33b.) The partitions usually are solid, in contrast to the open stanchions of the dairy barn. As in the dairy barn, there are individual stalls at one end.

The *sheep barn* may be open or closed. Open sheds are enclosed to a height only sufficient to prevent the sheep from getting out and to protect them from the wind. Closed sheds are of common barn construction. In wide sheds usually there are two rows of feed troughs with a center runway. Here, general lighting supplied by 60-watt incandescent lamps in reflectors mounted at the ceiling is recommended. In narrow sheds a row of similar units directly over, or not more than 4 feet behind, the single feed trough will be found satisfactory.

The *hog house*, especially the large-size community type, is somewhat similar to the enclosed sheep barn. Similar illumination is recommended.

The *general barn* areas usually are apportioned to each of the general farm activities. The lighting described under the specific types of barns should be applied to the individual portions. The haymow is located in the upper portion of most barns. With one 100- or 150-watt incandescent lamp for each mow, placed near the ceiling in shallow dome, angle, or RLM dome reflectors, barn work is facilitated. In some localities the regulations require the use of dust-tight equipment. Luminaires should distribute light over the driveway or floor space located below and between the mows.

Poultry Houses

The poultry house usually includes the hen house, the brooder house, and the feed room, all of which may or may not be under the same roof. Light is necessary for the proper care of the flock and the maintenance of the houses.

The *hen house* usually is illuminated for increasing egg production by extending the daylight period during the short fall and winter days.

For a 20-foot by 20-foot hen house two outlets should be provided, spaced at the ceiling 10 feet apart, and midway between the droppings board and the front of the house. (See Fig. 10–33c.) Shallow-dome reflectors should be used to provide the highest levels on feed hoppers, water pans, and scratching floor. Some light should be provided on the roosts also. Sufficient light usually is provided for morning or evening by two 60-watt incandescent lamps. Two 25-watt lamps will be adequate for all-night lighting. For large rooms, approximately one half a watt per square foot should be provided. Where lights are used in the evening they should be dimmed as the end of the period approaches so that the hens can see to get on the roosts before the lights are turned off completely. The dimming may be accomplished by operating an auxiliary circuit of 10- or 15 watt lamps alone for a sufficient time to allow the hens to roost before turning it off, or by means of dimming equipment. Clock or manual control may be used for both systems. Some poultry raisers use electric lighting only in the morning hours, eliminating the necessity for dimming equipment or auxiliary circuits.

The *brooder house*, in which chicks old enough to be transferred from the incubator are kept, usually can be lighted by one 40-watt incandescent lamp mounted close to the ceiling in the center of the room. Ultraviolet radiation frequently is used in both the brooder and hen house. (See page 16–16.)

The *feed room* usually will contain feed bins and auxiliary space for grinding, mixing, etc. Large storage spaces should be individually lighted by 40-watt incandescent lamps. Adequate general lighting usually can be provided by means of a centered RLM dome. The best arrangement is to have a luminaire opposite alternate bin partitions.

Silo

The silo holds preserved green feed for the stock. A silo is a cylindrical tank, usually 20 feet to 40 feet high, with an attached chute containing a ladder. A 100-watt incandescent lamp, mounted at the top of the chute, will supply illumination both in the silo and on the ladder. If mounted at the top of the chute, it should be tilted slightly toward the side of the silo so that it provides some light in the interior of the tank.

Farm Shops

Farms usually have a small workshop, a larger work shop for rough work on large machinery, and a machinery shed. The lighting of the small shop in which a work bench, forge, anvil, grindstone, and similar tools are located should follow industrial-lighting practice, with special care taken to see that individual machines located against the wall are supplied with light by local luminaires. The large shop and machinery shed should be lighted as storage spaces, unless the farmer performs difficult visual tasks in these rooms.

OFFICE LIGHTING

Seeing tasks in an office include the exacting ones of reading fine print, faint and blurred typing, and pencilled stenographic notes. Furthermore, many office workers use their eyes continuously throughout the working hours for these critical seeing tasks. Many factors in addition to the kind, arrangement, and number of light sources contribute to the seeing conditions. These include color and size of the paper used and the characters on it; contrast between paper and characters; and the reflectance and color of desk tops, office machines, furniture, walls, ceiling, and floor.

Seeing conditions should be appropriate not only for workers having normal vision but also for those having defective vision. In many cases there is a possibility that the work or seeing task may be simplified. Type sizes encountered in offices range from 6-point to 12-point. The latter (larger size) is preferable. Paper of high reflectance and dull (mat) finish provides the best contrast with dark characters. The physical proportions of certain forms, ledgers, and books may affect the visual task; the use of ink rather than pencil for notes and order forms usually is helpful. The use of convenient furniture which permits and encourages good posture may simplify the lighting problem. One difficult seeing task results from the use of large numbers of carbon copies prepared from worn-out carbon paper on low-reflectance copy paper.

Quantity of Illumination

In general, the more exacting the visual task, the higher the quality and the quantity of illumination must be supplied for the same ease of seeing. The illumination levels provided for tasks such as encountered in drafting, designing, bookkeeping, and office-machine operation (i.e., long periods of work on fine detail) should be higher than those provided for

casual and intermittent efforts. Such considerations were recognized in the preparation of the recommendations in Table 10-9. The recommended illumination levels should be maintained as a minimum in service on the work or in the space in which the given activity is carried on.

Quality of Illumination—Brightness Levels

Quantity and quality of illumination are related in offices as in all other areas. The standard of quality usually is higher in offices than in industrial applications, because of the relative ease of controlling office surrounds. Nevertheless, glare (both direct and reflected) is so commonplace that specific attention should be given it. Visibility usually can be improved by moving the light source from the line of vision, and by reducing its

Table 10-9. Recommended Values of Illumination for Offices*

CRITERIONS	FOOTCANDLES MAINTAINED IN SERVICE
Difficult Seeing Tasks	50
Involving:	
1. Discrimination of fine detail	
2. Poor contrast	
3. Long periods of time	
Such as encountered in:	
Auditing and accounting	
Business-machine operation	
Transcribing and tabulation	
Bookkeeping	
Drafting	
Designing	
Ordinary Seeing Tasks	30
Involving:	
1. Discrimination of moderately fine detail	
2. Better than average contrast	
3. Intermittent periods of time	
Such as encountered in:	
General office work except for work coming under "Difficult seeing tasks" above	
Private office work	
General correspondence	
Conference rooms	
File rooms	
Mail rooms	
Casual Seeing Tasks	10
Such as encountered in:	
Washrooms, and other service areas	
Reception rooms	
Stairways	
Simple Seeing Tasks	5
Such as encountered in:	
Hallways and corridors	
Passageways	

**Recommended Practice of Office Lighting*, Illuminating Engineering Society, New York.

brightness toward the eye. However, since room proportions and other limitations occasionally do not permit this, the choice of the luminaire becomes of paramount importance. Large-area luminaires should be of lower brightness than small-area luminaires. Discomfort is influenced by factors which also effect a reduction in visibility.

The quality of illumination in an interior depends on the brightness ratios in the field of view. It is recommended that the following maximums not be exceeded:

AREA	MAXIMUM RATIO
Between task and surround	3 to 1
Between task and remote surfaces	10 to 1
Between luminaires (or windows) and adjacent surfaces	20 to 1
Anywhere within the normal field of view	40 to 1

The brightness of luminaires in offices should not exceed 400 foot-lamberts in the zone between 45° and 90° above nadir.

Reflected glare frequently occurs because of the relative positions of windows or luminaires and of polished machine parts, specularly reflecting desk tops, and glossy paper. Glass desk tops, glossy papers, and glossy desk tops (especially dark ones) should be avoided. Even with such cautions the character of the task and surround may make some degree of specular reflection inevitable. Therefore, luminaire locations to the rear and to one side of the worker are to be preferred.

Harsh shadows and alternate light and dark areas in strong contrast are undesirable because it is difficult for the eye to adapt itself almost simultaneously to two brightness values in the same field. For this reason, local lighting, restricted to a small work area, is unsatisfactory.

The larger and more widespread the area of the luminaire, the softer and less pronounced the shadows will be. Light-colored walls and ceilings having a mat surface diffuse the light by reflecting it in many directions, thus tending to illuminate areas in shadow.

General Offices

The nature of a general office presupposes a relatively large area. Economically, it is desirable to obtain maximum utilization of the available space, keeping in mind that, over a period of years, desks and partitions may be rearranged several times. In modern practice electric lighting is provided to make possible efficient arrangement of office equipment independent of the available natural illumination. (See Fig. 10–34.) If practicable, the layout should be symmetrical, and, to minimize reflected glare, rows of luminaires should be run between desks rather than over them. The workers should face the least bright part of the luminaire. In most cases the end view of fluorescent-lamp luminaires presents the lowest brightness.

In choosing the type of general-lighting system to be used, it is desirable to establish in advance a set of specifications and to use the design which

most nearly conforms to the specifications. The following specifications should be carefully considered and weighed as to their relative importance in the case under consideration:

1. Standard practice: adequate illumination, proper protection against glare (both direct and reflected), proper distribution of light, and uniformity of illumination.
2. Efficiency of the system per unit of light emitted: this affects the operating cost and the heat load in the area.
3. Maintenance: ease and expense of cleaning, service convenience.
4. Sturdiness: long life, low service cost.
5. Appearance: in conformance with occupancy and architectural design of the interior, lighted and unlighted.
6. Flexibility: opportunity to increase light output at some future time, outlets so located that partition changes can be made without relocation of luminaires.
7. Heat: temperatures and methods of disposing of excess heat.

Supplementary lighting. For general office work, supplementary lighting on the desks usually is not desirable because of the difficulty of lighting a large enough area to include the entire working surface, and because of wiring difficulties. Local or supplementary lighting can be designed for business machines where the visual task usually is located on a sheet of paper or card fastened in some sort of holder or rack in a fixed position. Also, since the machines, as a rule, are electrically operated, power already is available at the desks or tables.

In providing supplementary illumination for an area, it is important that adequate general lighting be provided also. Otherwise, there is likely to be too great a contrast between the relatively bright work and the dark surroundings into which the operator looks every time his eyes are raised. The ratio between task and surround brightness is important. For greatest comfort the brightnesses should be nearly equal.

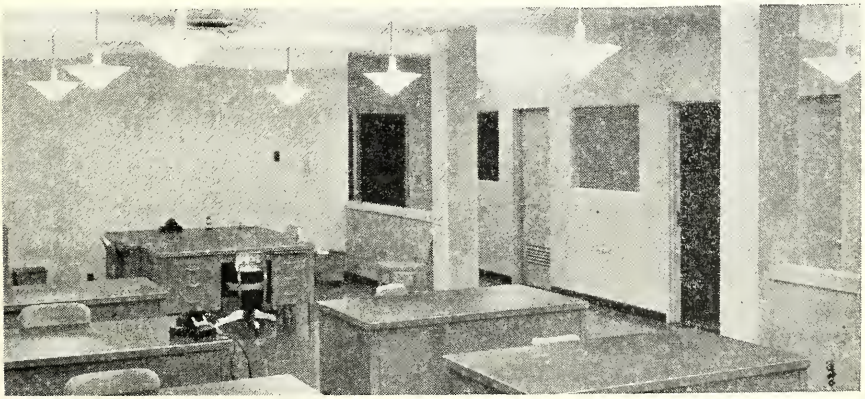


FIG. 10-34. Indirect luminaires with 500-watt incandescent lamps spaced on 10-foot centers provide an illumination of 25 footcandles of well-diffused light in this general office.

Private Offices

Conditions in a private office vary in character but may be classified as follows:

1. Occupant working alone or dictating to secretary.
2. Occupant conferring with one or more visitors.
3. Secretary working at a desk.

In the first classification the seeing task may be severe. In most cases, however, it is intermittent in character. In the second classification the seeing problem is the examination of reports and records. In the third classification the seeing problem is similar to that of the general office, and the secretary's desk should be provided with the illumination recommended for the most severe task encountered. In meeting these conditions, two basic differences between general and private offices are recognized. The first is that in the private office there is far less latitude in furniture placement with reference to windows and walls (both possible sources of glare) than in the large general office. Second, the co-efficient of utilization is small for small rooms and, therefore, other things being equal the wiring capacity (watts per square foot) must be greater for equal illumination. Another difference is that private offices more frequently have glass partitions, glass-covered pictures, glossy furniture, and glass-covered desk tops. All are potential sources of reflected glare.

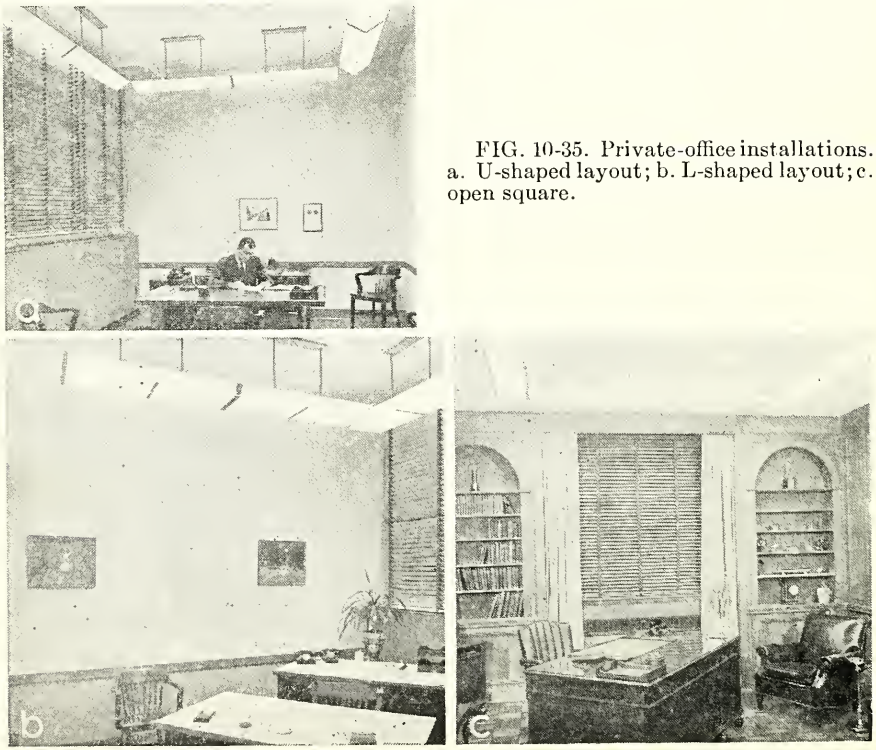


FIG. 10-35. Private-office installations. a. U-shaped layout; b. L-shaped layout; c. open square.

The luminaire design and layout is particularly important in private offices. The following plans have been found to have advantages when the luminaires have a considerable direct component. (See Fig. 10–35.)

U-shaped layout. For the small narrow office in which the occupant often sits between a desk and table, luminaires can be arranged in a U-shape with the open part away from the window, and the closed (or cross piece) approximately over the occupant.

L-shaped layout. For the small square office, with diagonal desk and table arrangement, the L-shaped layout can be used with the apex of the L approximately over the furniture in the corner and the legs of the L parallel to the walls. If possible the natural lighting should enter from the occupants' left (for right-handed persons).

Open square. When several individual luminaires are to be used, their arrangement to form an open square may be advantageous as compared with spotting them at existing outlets.

Supplementary center panel. To supplement a symmetrical layout, a large-area luminaire can be used if so arranged that it supplies direct illumination on the work area and maintains comfortable brightness ratios without introducing reflected glare.

Conference Rooms

It is common practice to provide more elaborate interior decoration in board of directors' and conference rooms than in outer offices, and the lighting in these rooms usually conforms to the architectural style of the interior. Not less than 30 footcandles should be provided over a conference table, and the illumination should be diffused to eliminate shadows on the faces of persons seated around the table. Undesirable reflections from the table surface should be avoided. (See Fig. 10–36.) High-reflectance mat surfaces are recommended.

Reception Rooms

For reception rooms, a general level of 10 footcandles should be provided. If the receptionist does stenographic and clerical work, the higher illumination required should be provided by supplementary sources. Unless ample general illumination is furnished such equipment should be available for use also by persons who wish to read while waiting. (See Fig. 10–36.)

Drafting Rooms

Drafting makes very serious demands upon the eyes, since it involves accurate discrimination of fine details, frequently over long periods of time. A high level of glareless illumination should be provided. The contrast between the work and the background may be very poor, as, for example, when tracing a faint blueprint or a worn pencil drawing. Reflected glare from a specular drawing surface as well as from the polished T square, celluloid triangle, or scales may be particularly annoying and should be avoided. Care must also be taken to eliminate shadows along the drawing

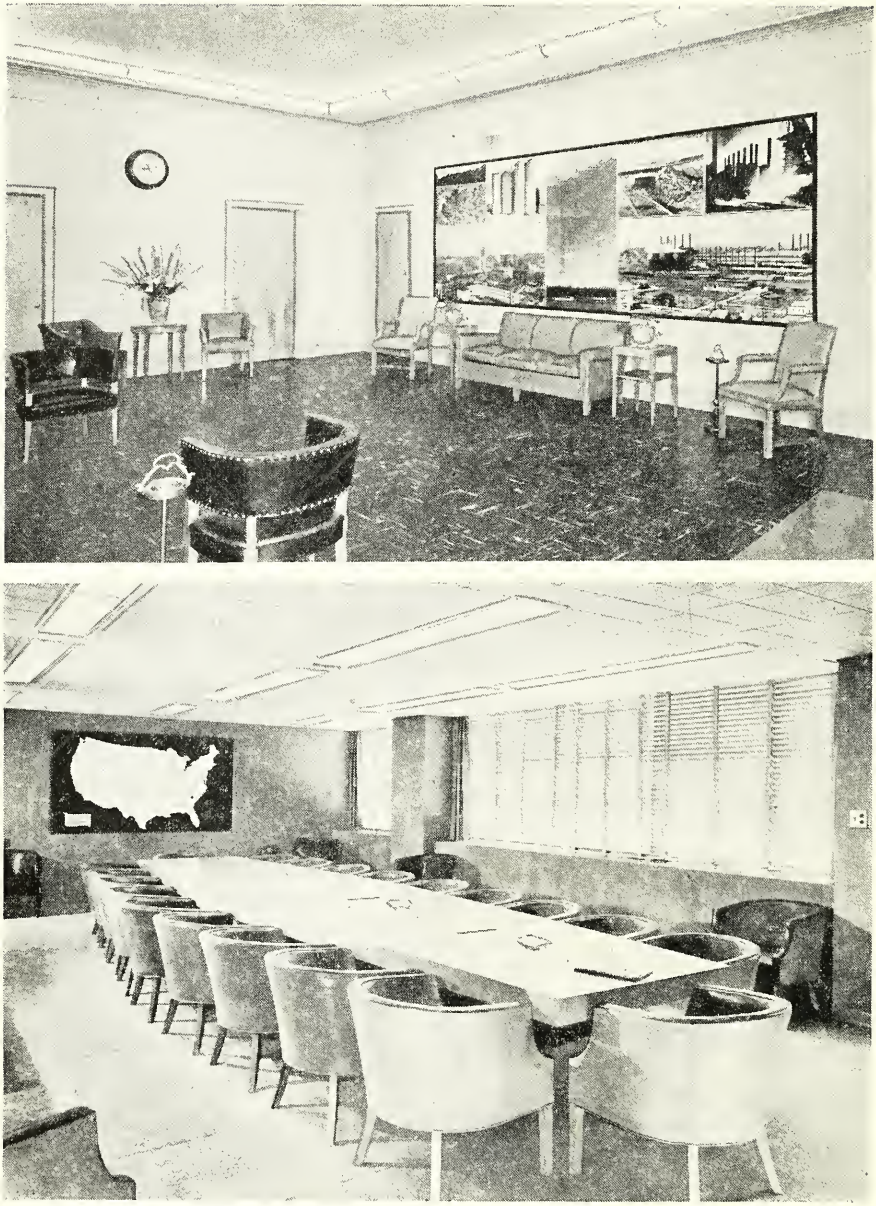


FIG. 10-36. Attractive reception room and conference room.

edge of the T square or triangle as well as multiple shadows from the drawing instruments or the draftsman's hands. On horizontal boards any ceiling or luminaire brightness may be reflected by the work to the eyes of the draftsman, and also the T squares, triangles, and curves may cast shadows. With the board in a vertical position, specular reflections cause little if any discomfort, and shadows are minimized. Furthermore, the



FIG. 10-37. Lines of luminaires are run diagonally across the ceiling of this drafting room to eliminate shadows at working edges of T squares and triangles under most circumstances.

board may be high enough to shield the eyes of the draftsman from luminaire brightnesses otherwise in the field of view. Where boards are horizontal, straight edges of T squares parallel to line sources of illumination may cast sharp shadows unless the edges are leveled. To eliminate such shadows when the straight edge is parallel to the long side of the drafting table, it is recommended that this side be placed at an angle of 15 to 20 degrees with the lines of lighting equipment (Fig. 10–37).

A drafting table with a frosted or white glass top illuminated from below to a brightness on the order of 300 footlamberts is recommended for use in tracing in rooms with 50 footcandles of general illumination. This is a method of solving a problem which is most difficult to accomplish by overhead lighting. It is desirable to keep the temperature of the tracing table as low as possible; therefore, light sources having a high lumen-per-watt rating should be selected. The desirable brightness of the glass depends on the nature of the work and the level of illumination from above. The draftsman should use opaque paper to cover the portion of the glass which is not concealed by the drawing in order to avoid the direct glare which would otherwise be experienced.

Office Machines

The seeing problems involved in the operation of business machines can be divided into three classifications: (1) locating keys, buttons, levers, and other controls on the machine itself; (2) reading printed, typed, or handwritten material from which the operator must operate the machine; (3) reading the results on the machine dials.

Machine operation. The operation of most business machines does not present a difficult seeing problem and skilled operators do most of the work by the touch system. Letters or legends on the various keys are used as checks and during the training period. The general office lighting is adequate.

Seeing the work. The copies of invoices, lists, etc., which the business-machine operator must transcribe accurately usually represent the most

difficult seeing task in a modern office. The paper often is of poor quality and the characters nearly illegible, especially on sixth or seventh carbon copies, which are not uncommon. Contrast is likely to be very poor. Higher illumination is necessary if acceptable visibility is to be obtained. One hundred footcandles is recommended for this type of seeing task. In order to provide this illumination on the work the use of supplementary lighting is recommended.

The luminaires should have low brightness so as to avoid specular reflections. The light sources should be shielded from the direct view of the operator and others in the room. Where the operation requires rapid switching of visual attention between the machine and the work, it is desirable to have the brightness of the machine approximate that of the work.

Reading results on dials. The reading of the dials of business machines may be difficult, particularly when the dials become worn. Often the best way to solve this problem is by building a light source into the structure of the machine.

Machine finishes. Though most office machines such as typewriters, addressographs, billing machines, and so forth have some glossy external parts that reflect incident light in such a manner as to annoy an operator, some recent models may be obtained with a higher-reflectance mat finish than has previously been considered standard. Glaring reflections from flat specular surfaces can be overcome by proper orientation of the luminaires, but convex specular surfaces such as rods, buttons, and bands may cause trouble regardless of the luminaire orientation. Dark finishes have been almost universal, yet, between white papers in or about the machine and the dark machine surfaces, undesirable contrasts result that may be very fatiguing to an operator. Dark desk tops also can be a source of visual discomfort. It is recommended that all polished specular surfaces be eliminated from machines. It is recommended also that the machines themselves, as well as the desk tops on which they are installed, be finished in "light" colors (reflectance of the order of 30 to 35 per cent).

Files

General correspondence files often are arranged in a rectangle around a file clerk's sorting desk. This permits easy access to the files and allows a general overhead lighting system to illuminate the desk, the vertical faces of the files, and the opened drawers. The general lighting system should provide not less than 30 footcandles on the work plane. (See Fig. 10–38.) The seeing problem for ordinary correspondence and card files is concerned with inclined and vertical surfaces, and the seeing is by means of brightness and color contrasts. Though much file material is white, colored stock often is used. Such surfaces may be satisfactorily illuminated by a well-diffused, general-lighting system of the indirect or semi-indirect type, or by a direct large-area, low-brightness source. This type of illumination results

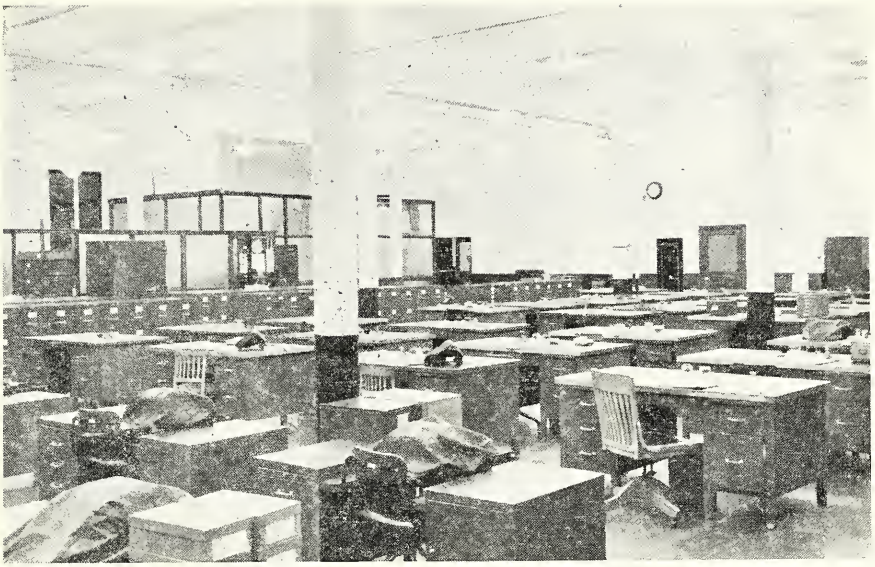


FIG. 10-38. An office, including files, business machines, typing, and work desks, lighted with plastic luminous-bowl indirect luminaires.

in a minimum of shadow in a typical opened file folder; and the person observing the files does not cast a sharp shadow over the work. In spaces where files are opened only occasionally and the room conditions do not permit well-diffused illumination, direct-lighting sources may be found satisfactory. Direct-lighting luminaires should be mounted above the aisle space between the files so that the downward light may penetrate the folders in the drawers. In some types of filing systems, a number of overlapping cards in trays or drawers are held in position at the bottom edge by a specularly reflecting transparent material. The index and other printed or typed matter appear along the bottom line of the cards and are viewed through the transparent material. When illumination is provided by a general overhead system of direct or semidirect luminaires, one or more may be seen reflected specularly from the transparent material, making it difficult (frequently impossible) to read the printed matter. Because of the various angles at which the trays may be placed, it is difficult to position supplementary units at any point in the immediate areas above the files so as to avoid specular reflection. However, if by providing a fairly high level of illumination with indirect lighting, or large area sources having relatively low surface brightness, the brightness of the specular reflection from the surface of the transparent material may be reduced to little more than the brightness of the surface beneath, it will not interfere with one's vision. In many catalogue files, the catalogues are arranged vertically as are the books on book shelves. An illumination on vertical files of about 15 footcandles usually will accompany a level of 25 to 30 footcandles on the horizontal.

Service Areas

Mail room. For the variety of seeing tasks encountered in a mail room, 30 footcandles of uniformly distributed illumination is recommended.

Corridors and passageways. Any passageways not separated from the working space by high partitions should have the same general illumination as the rest of the office space. In corridors and passageways having high partitions, lower levels of illumination may be adequate. If the partitions are of glass so that the lighting equipment is visible from the rest of the office, the same restrictions with respect to brightness of the luminaires should be observed as in general office space. Outlets should be placed at locations such as corridor intersections, in front of elevator doors, and at the top and bottom of stairways. Luminaire spacing should not exceed about $1\frac{1}{2}$ times the mounting height to achieve a reasonable degree of uniformity.

Stairways. Luminaires in stairways should be located so that persons do not cast shadows of themselves over the stairs, so that stairway treads are not in shadow, and so that glare at eye level is avoided. In general, an overhead luminaire should be located at each landing. The arrangement should be such that adequate illumination will be provided after allowing for the failure of any one lamp. Recessed luminous elements in the walls near the floor often are advisable near landings and especially where one or two steps connect different elevations in corridors. A change in the color of the floor or baseboard at these locations also will assist in calling attention to the change in elevation of the floor level.

Lavatories. In these areas a general lighting system which will provide not less than 10 footcandles is recommended. Mirror lighting is desirable in rest rooms and wash rooms. (See the discussion of bathroom lighting, page 10-43.)

STORE LIGHTING

No field of lighting presents as many or as diverse problems to the designer as that of lighting the modern store. No two stores are alike. They range in size from small one-man operated shops to large department stores with hundreds of employees. The merchandise displayed and sold in these areas varies in size from needles to automobiles, in texture from polished metalware to wool blankets, in reflectance from black worsteds to white sheets, and through all the colors of the rainbow. Some kinds of merchandise are transparent or translucent, others opaque. Vertical surfaces are the important ones to be appraised in some cases, in others it is the oblique, rounded, or horizontal surface that the customer inspects when buying. It is evident that the store-lighting designer must be versatile and able to apply all the lighting tools and techniques.

To make its full contribution to successful, profitable merchandising, store lighting should be planned not only to provide favorable conditions for rapid and accurate evaluation of the inherent qualities of merchandise, but also to attract attention to the store, to dramatize the store and its

specific features, and to make most effective all the other appointments of the establishment. In large proportion, the latter (architectural form, decoration, materials, fittings, layout) are designed to have the appealing appearance required by modern visual merchandising methods. When approached from this viewpoint, a store becomes a pattern of brightness and color varying in significant steps to attract attention, stimulate intelligent buying and selling, and create a favorable, lasting impression.

Store lighting should be planned with the following objectives in mind: controlling traffic; influencing circulation, speeding buying decisions and impulse purchases; increasing sales per customer per square foot per sales person; and increasing over-all profit.

Representative of the illumination values which have been found effective in stores are the following, arranged in steps which are significant from the standpoint of attention value:

Circulation areas	20	footcandles
Merchandising areas	50	"
Show cases, wall cases, counter displays, etc.	100	"
Featured displays in store and in window	200	"
" " " "	500	"
" " " "	1,000	"

In some low-volume establishments in very light traffic areas somewhat lower values may suffice, whereas competitive conditions and the sales potential in other situations may dictate higher levels than those recommended. In any event, flexibility in the facilities provided, especially for accent lighting in store and window, adds greatly to the value of the system.

Store Luminaires

Store luminaires have a three-fold function: (1) to shield the customer's eyes from the brightness of lamps; (2) to direct light from a bare lamp from the angles where it is not wanted, or where it creates glare, to angles where it will contribute to the merchandise brightness and the interior brightness pattern; and (3) to enhance the decorative plan and to contribute to the architectural effects.

Functions of Store Lighting

Store lighting should (1) help attract attention to the store and its merchandise; (2) produce facilities for good seeing so that shoppers can judge the qualities of purchasable items accurately and quickly; and (3) create a store interior which is a pleasant and comfortable place in which to shop and sell.

Store lighting design is not standardized. Although by chance many stores are lighted similarly—corner drug stores, for example—yet there is no incentive to attempt any such standardization because store owners seek to obtain individuality. Store lighting is, to a degree, allied with stage lighting in that both require good showmanship.

Attracting customer attention. Although some owners operate on the assumption that their store is a warehouse of merchandise to which people can come when they wish to purchase needed items, most stores feel the need for getting and holding customers' attention, and consequently employ such modern promotional methods for drawing shoppers to their stores as radio, printed advertising, posters and signs, and brightly lighted stores and show windows. The primary function of store lighting for both owners and shoppers is to draw attention to items of merchandise. By lighting cases and other displays the merchandise brightness can be increased to give the articles display value. (See Fig. 10–39.)



FIG. 10-39. Good store lighting increases merchandise brightness and background contrasts and thus attracts customer attention to items on display.

Evaluating merchandise. Store lighting should create a favorable seeing condition at the point-of-purchase by which a shopper can quickly and accurately appraise the inherent qualities, color, texture, form, and workmanship of merchandise. Lighting for this purpose can be extended also to setting up lighting conditions such as those that exist at the seashore, or in a ballroom, so that customers can accurately appraise the merchandise as it will be seen at the point of use. (See Fig. 10–40.)

The problems of lighting for attractive display, and lighting for correct appraisal, overlap for many articles that are handled as both display and stock items. Normally such items are displayed in show cases, wall cases, on shelves, and in garment cases, but can be removed for closer inspection and purchase. Since the merchandise will be seen in both locations—display and purchase point—it is evident that the lighting for these two

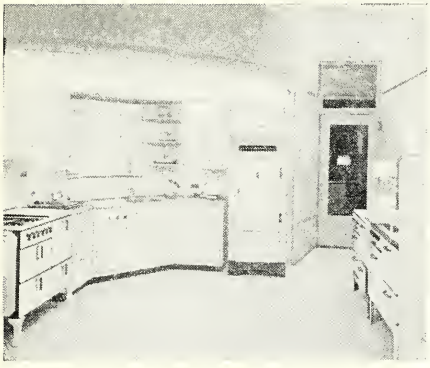




FIG. 10-40. Lighting aids in establishing an atmosphere conducive to accurate appraisal of merchandise with respect to its ultimate appearance in use, indoors or out.

locations should be so related as to color, level, and quality that it will suffer no change in appearance when moved from one point to the other.

Lighting for the quick and accurate appraisal of merchandise is of first importance to shoppers, but is of benefit to the store owner also. It speeds the selling function and helps to reduce the number of items returned for credit because of their changed appearance when seen under the lighting at the point of use.

Store appearance. In order that their stores may impress shoppers favorably and thereby induce them to linger, buy, and return, store owners strive to create an atmosphere which is consistent with the kind of merchandise sold and acceptable to the store's clientele. For example, the kind of surroundings desired in an infants' wear shop is different from that needed in a hardware store.

The picture-impression of a store is the summation of all of the visible elements (arrangement, furniture, displays, lighting, etc.) but some elements weigh more in this picture-impression than others. It is believed that the brightness pattern is the dominant element in this picture. (See Fig. 10–41).

Factors That Influence Seeing and Buying

Although shoppers may use all of their senses in appraising merchandise, the sense of seeing is undoubtedly important. The tone of a piano is important, but so is the kind of wood in the case and its finish; the fragrance of perfume seems more alluring when the container is attractive also; the materials, workmanship, and styling of shoes, as much as their fit, is reflected in their price; salads are selected by cafeteria patrons by their appearance.

Time. The human eye requires time to see. All other factors being equal, objects illuminated to higher footcandle values with resulting higher brightnesses can be seen in less time than those of lesser brightness.

Size. Large objects, and large details of pattern and texture, are easier seen than small ones. Appraisal often requires the study of small details of

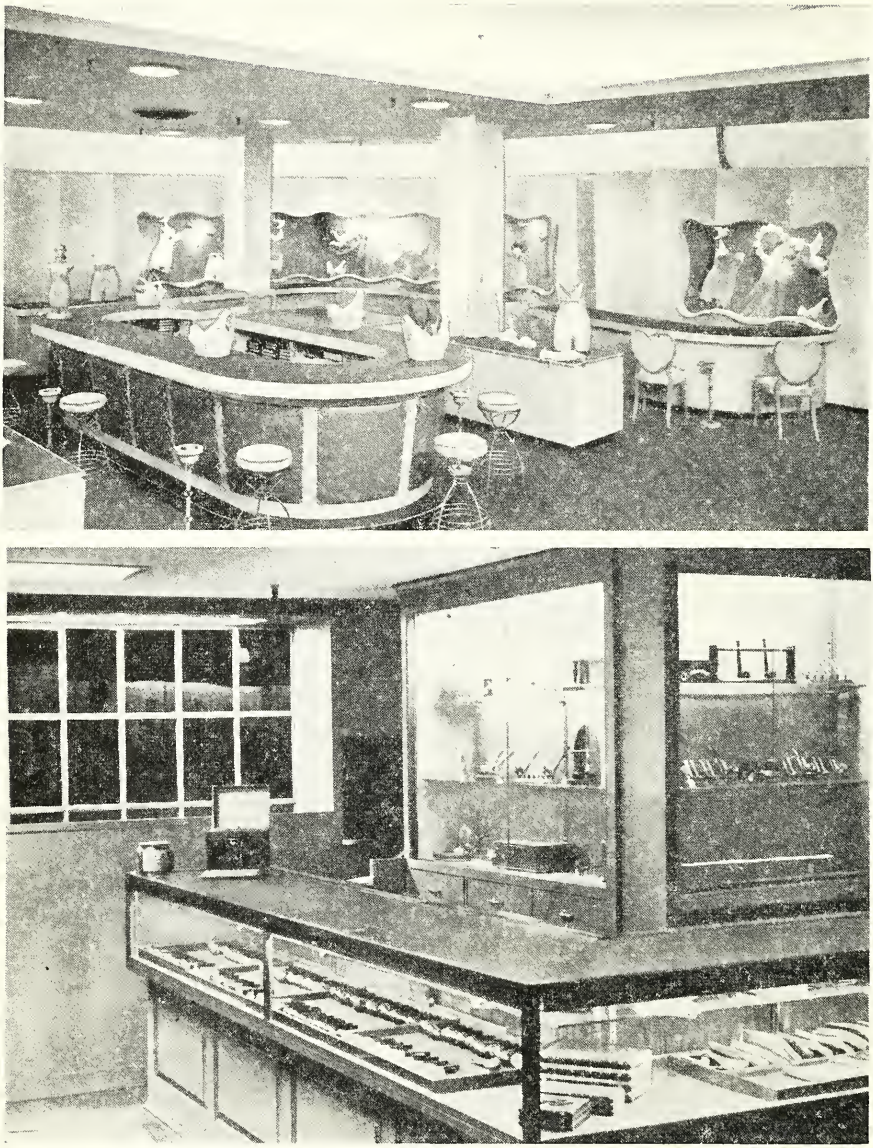


FIG. 10-41. A lighting installation contributes to the over-all appearance of a store and should be planned with the character of the merchandise and clientele in mind.

workmanship, label copy in small type, or intricate pattern details; higher illumination values have the effect of making them easier to see. This is of particular value to older persons and others who have subnormal vision.

Contrast. A high contrast between an object and its background is of value in attracting attention to displays. Dark objects displayed against light backgrounds are noticed more quickly than those viewed against

dark ones, and vice versa. A displayman needs a versatile array of lighting equipment (background lights, spotlights, floodlights, color filters, etc.) to create these contrasts. Each display should be considered a miniature stage setting designed to draw attention to a specific area, and to make the merchandise shown there attractive to shoppers. Contrast can be obtained by brightness and color differences between objects and their surrounds.

Brightness. The end product of illumination and reflectance is brightness, which attracts attention and aids in seeing.

Reflectance. The reflectance of a wall, ceiling, or merchandise surface indicates the proportion of incident light that will be reflected. Reflectance therefore controls brightness. It is important to know the character of the reflection as well as its value. For example, a white tablecloth, a white china plate, and a polished silver cream pitcher may have the same reflectance (80 per cent). The cloth, however, reflects its light diffusely and looks equally bright seen from any angle; the china plate looks white also, but its glazed surface adds specular reflections; the polished silver cream pitcher looks dark except for the reflected highlights of light sources and bright surrounding.

In order that unwanted and uncontrolled reflections in wall and ceiling areas may be avoided, surfaces that have diffusing, or near-diffusing, characteristics are recommended. These characteristics are typical of mat and eggshell finish paints, wallpapers, woods, etc.

The use of color. Accurate merchandise appraisal depends in part upon the color quality of the lighting. A fluorescent lamp may produce a daylight quality light and an incandescent-filament lamp a reddish yellow light. Each affects the apparent color of merchandise. Lighting that fails to show merchandise as it will appear under the lighting where it will be used often is responsible for a customer's dissatisfaction and return of the goods. Returns may be as much as one-eighth of gross sales in some stores.

In addition to affecting the apparent color of merchandise, the color quality of illumination has an important bearing on the atmosphere and the decoration of a store. The complexions of customers and salespeople are affected also. This is especially important in fitting rooms for men's and women's wearing apparel. If the lighting does not complement the complexion, it will affect adversely the approval of the fitting. It is recommended that light of a "warm" color be provided to enhance facial appearance.

Design Factors in Store Lighting

Most stores need a good balance of horizontal and vertical illumination. Luminaires having a light distribution normally used for general lighting purposes usually will produce not more than half as much illumination on vertical as on horizontal surfaces. (See Fig. 10–42.) While common interior lighting layout procedures are designed to provide uniform illumination on a horizontal plane, many objects (wallpaper, draperies, tapestries,



FIG. 10-42. In many stores, light on vertical surfaces is at least equal in importance to that provided on horizontal surfaces.

paintings, clothing, etc.) are displayed and appraised vertically. Also, shelves at the perimeter of many stores are important display areas. These may be lighted by asymmetric distribution equipment supplementing general lighting. If luminaires that have strong horizontal components are selected for general lighting, it should be recognized that they may be uncomfortably bright also. There is less danger of this in small areas with luminaires high enough above the floor to be out of the customer field of view.

Luminaire brightness and contrast with ceiling. Whether luminaires are glaring or not depends upon their brightness relative to that of their surround. Luminaire brightness may be reduced by shielding or by concealing the equipment from the normal field of view. (See Fig. 10-43.)

Highlights. Highlights are useful in revealing the form of semispecular objects such as silks, leathers, glassware, pottery, etc. Highlights created

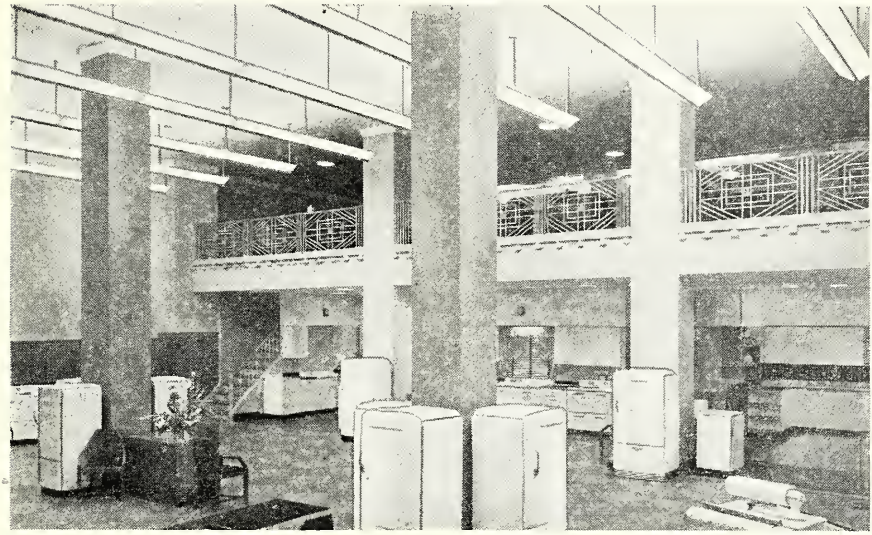


FIG. 10-43. To minimize glare from luminaires, they should conceal the lamps from view. The luminaire brightness should be not much greater than that of its background. High reflectance ceilings and upper wall surfaces and some indirect light component aid in reducing contrasts.

by concentrated incandescent-filament sources are essential for displays of diamonds, jewelry, etc. Large-area, low-brightness highlights are more suitable for automobiles, furniture, and similar objects. (See Fig. 10–44.)

Shadows. Downlighting creates shadows that are sharp and dramatic. Indirect lighting and large-area diffusing sources produce soft shadows that tend to flatten the appearance of rounded objects and conceal surface textures. Shadows help to reveal the form of objects and texture of materials. (See Fig. 10–45.) They should not be so dense that they conceal merchandise on shelves or in cases. Sharp shadows on customers' and clerks' faces usually are not flattering.

Maintenance. Proper maintenance of a lighting system pays dividends. The amount of light absorbed in dust and dirt on transmitting and reflecting surfaces may equal that which reaches the merchandise. Regular maintenance is made inexpensive when lighting equipment is easy to clean and lamp changes are easy to make. Group replacement of all lamps at some predetermined point in their life may be the most satisfactory procedure. (See pages 6–2 and 10–20.)

General Lighting of Stores

General lighting is necessary in every store. For certain kinds of stores and types of merchandise, uniform general lighting providing the recommended level of illumination is by itself satisfactory. Food markets, variety stores, and others that display items primarily on open, closely spaced tables and counters are in this category. (See Fig. 10–46.) Usually, few display cases are used and perimeter shelves are considered principally as stock rather than display areas.

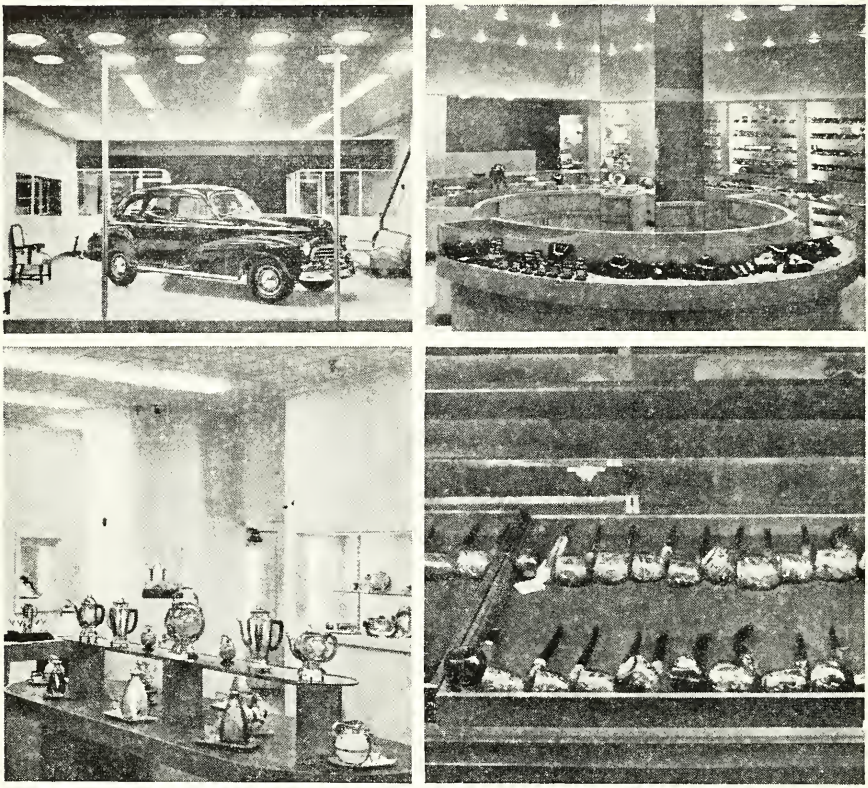


FIG. 10-44. Highlights assist in displaying specular and semi-specular surfaces and refractive materials to best advantage. Point sources are required to make gems and glassware sparkle. Large areas of brightness add the sheen to glossy surfaced merchandise.

Interior-Display Lighting for Stores

Stock merchandise located and arranged for display is a large and important portion of display in the average store.

The ratio of illumination on the merchandise in its display position to that at its final appraisal point should be planned for maximum display value and minimum appearance change. Usually, if the ratio of illumination inside the case to that outside is approximately 2 to 1, the merchandise will have adequate display value without suffering in appearance when removed for appraisal. An illumination level inside glass-enclosed cases twice that incident on glass sides and top compensates for surface reflections that reduce the visibility of the merchandise. In order that customers may see through these surface reflections, the brightness inside must be higher than that of the surface reflections. Internal illumination is particularly necessary in glass-enclosed wall cases because, unless luminaires are located close to perimeter walls or supplementary units are provided, the general illumination level usually is lower at the room perimeter than at the center.

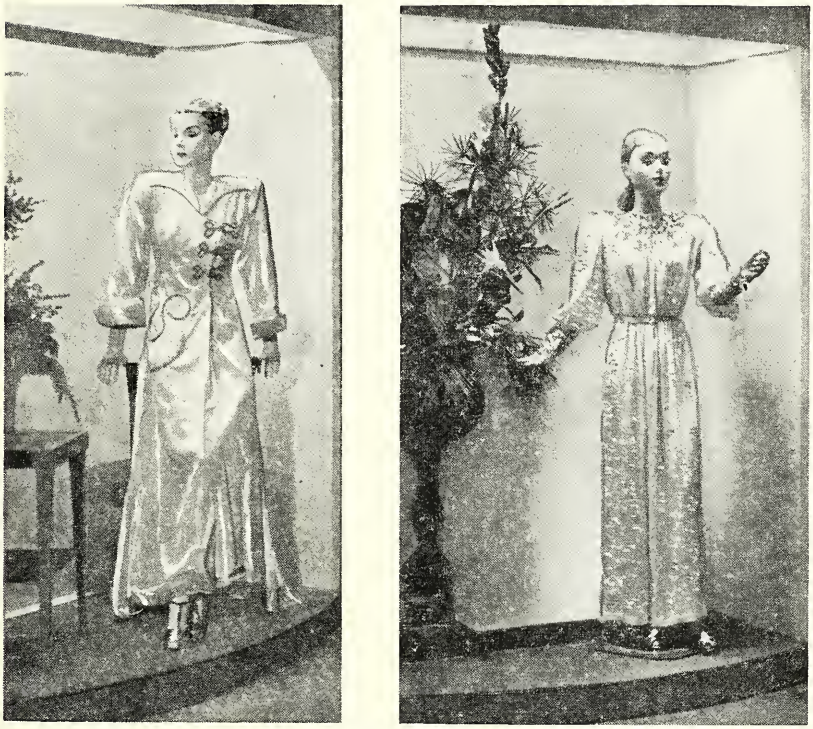


FIG. 10-45. Shadows produced by carefully controlled beams of light can create dramatic effects, bring out flowing lines, and reveal the texture of mat-surfaced materials.

Mirrors. Since shoppers commonly use mirrors to appraise articles of clothing in which they are interested, accent lighting at mirrors is important. The place where the shopper stands or sits, rather than the mirror, should be illuminated. A mirror may be used as a reflector to light the lower part of the figure. Three things are important: the face should be illuminated with diffused light of a color that flatters the complexion; the sales item should be adequately lighted over its entire surface; the quality of light should be planned to display best the type of materials most often sold in the area.

Vertical displays. Clothing, floor and wall coverings, and tapestries and draperies often are hung vertically for display and appraisal. Uniform illumination from top to bottom is desirable. (See Fig. 10–42.)

Column displays. The utilization of columns (especially the large columns found in many old buildings) as display centers not only helps to conceal the columns but adds appreciably to the display footage. (See Fig. 10–47a.) Such display destroys over-all supervisory visibility also, and therefore may not be acceptable in all cases. Troughs, built-in luminous elements, and remote spotlights are effective.



FIG. 10-46. In stores that display items on open, closely-spaced tables general lighting often is used alone.

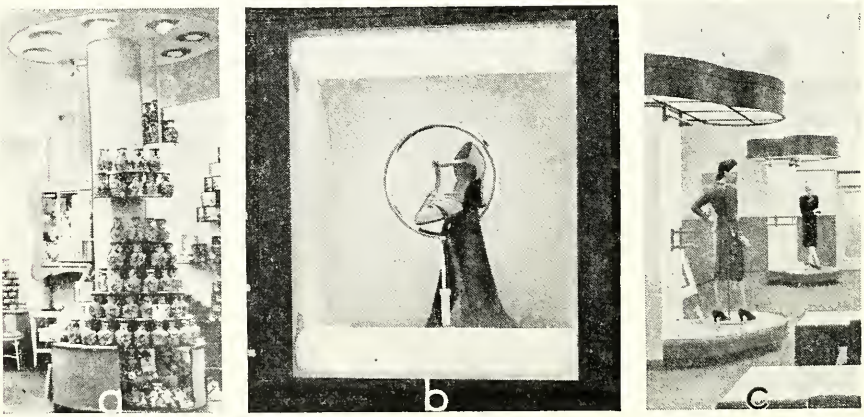


FIG. 10-47. a. Column displays. b. Display niches. c. Canopied displays.

Niches. In departments where stock is concealed and merchandise is small in size, display niches can be effective. These niches usually are lighted by built-in equipment. (See Fig. 10–47b.)

Canopies. A canopy is an effective device for attracting attention to a display grouping or for emphasis of certain merchandise. (See Fig. 10-47c.) It also may divert attention from a bad ceiling conditon. Canopies form useful ledges behind which tubular indirect lighting may be concealed. Further, they can serve to lower portions of ceilings to conceal more efficient (shorter projection distance) downlighting.

Platform and dais displays. The preferred mood to be created by an open platform or dais display is freedom and spaciousness. (See Fig. 10-48.) Light from a remote location, e.g., a near-by column or the ceiling, is desirable. The light may be trained and controlled by means of spot reflectors, reflector lamps, or floodlights.

Counter displays. Overcounter lighting may provide background accent, silhouetting, or direct illumination, depending on the merchandise and effect desired.



FIG. 10-48. Platform and dais displays often are lighted by remotely located projectors.

Directional signs. Since the colors of illumination that may be applied in most displays are limited, color stimulation often is used in directional signs as well as in wall decoration, upholstery, etc. Many opportunities exist for carrying advertising or directional messages on walls, canopies, column displays, etc. (See Fig. 10–49.)

Window Lighting for Stores

Show windows fronting on a high-density pedestrian traffic-way are one effective medium for informing the public of items for sale and of inviting them into a store. They are the physical bond between the street and pedestrian-way and the store interior, and they can be made a stage on which a merchant's goods are dramatized. (See Fig. 10–50.) Show-window lighting should be versatile, often almost as flexible as stage lighting, and it should supply brightness, which attracts attention and minimizes veiling glare. Many modern windows are decorated as a foreground for a view of the store interior. This is called *open-front* design.

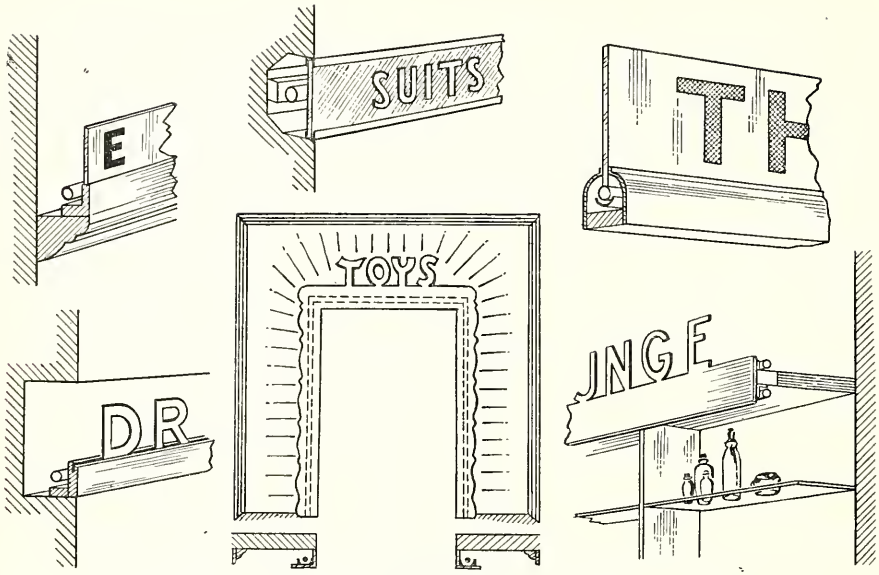


FIG. 10-49. Directional, departmental, and advertising signs.

General lighting. High-level general illumination usually is the first requirement in show windows. However, in large prestige-type stores dramatic accents sometimes are considered more important. Often a window is illuminated to compete at night with other neighborhood lighting, or to display merchandise successfully under adverse daytime conditions created by window-glass reflections of sky brightness or other daylighted areas.

Accent lighting. Emphasis or accent lighting is provided by individual spotlights which sometimes are used with dramatic effect, even without general diffuse lighting.

Supplementary lighting. In certain types of windows, footlights are desirable because of the difficulty of projecting light to the face or the merchandise (which the pedestrian sees) from luminaires located directly above. Footlights are effective also when a geometrical disposition of the glass to eliminate reflections caused by daylight-created brightness is desirable, and overhead lighting is difficult to use effectively without creating reflected glare.

Because a show window has the prominence of a stage and compares with it as a center of attraction, lighting equipment should be located carefully so as not to create glare. A luminaire should not attract attention to itself. The common concealment techniques (valances, flush and recessed mounting, and louvers) provide satisfactory results when planned for all angles of viewing. Normally, there is no need to protect from glare at the back of the window.

Open fronts. With open-front windows in particular, and with other types also, the window orientation with respect to sunlight and skylight is



FIG. 10-50. Closed- and open-back store windows and a typical open-front store.

being given increased study. From a practical standpoint, it is impossible at present to build up the illumination level in a window sufficient to overcome completely the veiling glare produced by bright sky reflections, sunlit light-colored buildings, and other adverse conditions. Studies have indicated that when the average reflected brightness is twice the brightness behind the window glass, the reflection is at the threshhold of producing deleterious veiling glare. Many architectural methods have been developed for the practical solution of this problem. These include sloping windows, which reflect lower brightness areas such as those of which the brightness can be controlled by awnings, marquees, or canopies. (See Fig. 10–51.)

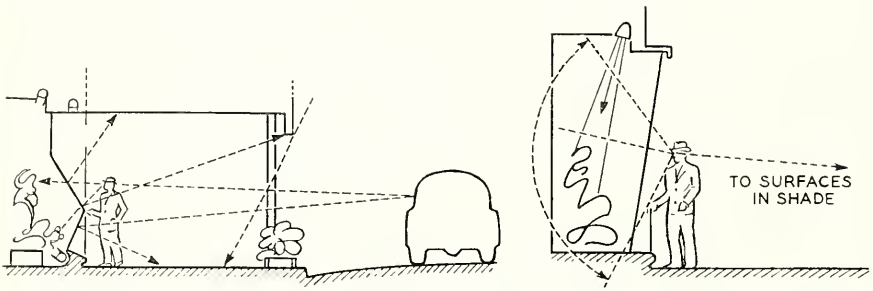


FIG. 10-51. By proper orientation and shading of glass surfaces, the brightness of reflected images in the pedestrian field of view may be reduced below that which interferes with viewing the window display.

SCHOOL LIGHTING

The trend in education toward greater dependence on visual techniques emphasizes the importance of lighting in schools. Illumination aids materially in the accomplishment of the visual tasks encountered by students and teachers and, in so doing, is beneficial in preserving good vision, aiding impaired vision, minimizing visual strain and fatigue, and increasing the over-all efficiency of the educational process.

Also, it is recognized that the provision of a model environment for health and happy living and work at the formative stage in a child's development is one of the contributions which classroom experiences can make to his general education. By using the techniques available today, light sources, equipment, materials, and proper natural and electric illumination in combination with high-reflectance room and furniture finishes can provide attractively colorful and cheerful, yet comfortable and efficient, seeing conditions for students and teachers.

Despite the existence of these techniques and the availability of the equipment and materials required to put them into practice, many schools make poor use of natural illumination and have no provision for electric lighting.

School routine has much to do with this indifference toward lighting. Ordinarily, the hours that a classroom is used each day are few, and intentionally most school buildings are constructed, located, and oriented to make available as much daylight as possible. However, it is only within

recent years that the close relationship among interior decoration, seating plans, and utilization of daylight has been recognized.

Electric illumination is required during the winter and on cloudy and stormy days to compensate for reduced daylight levels and, because of crowded conditions in many urban areas, to make possible staggered and evening sessions.

Classroom Characteristics

The commonly accepted area unit of school lighting is the classroom with provisions for seating twenty to forty pupils at individual desks. Certain features of such typical classrooms are of special interest with respect to lighting.

Seating. Most classrooms are designed for distributed seating, making it advisable to plan the lighting for uniform results throughout the entire room. In older schools seats invariably are arranged so that all pupils face in one direction. While this still is a dominant plan, there are a considerable number of exceptions, especially in the lower grades. Here groupings of six to twelve around individual tables is an accepted practice.

Daylighting. The greatest number of classrooms are arranged with large windows dominating an entire wall to the left of the pupils as they face the front of the room. This window space has a strong influence on brightness ratios, since it is seldom that daylight is absent during regular school hours.

Sight-saving classrooms. One of the most serious problems in school lighting arises in connection with pupils whose eyesight is so defective as to justify special consideration. It is standard practice in some school systems to place such pupils in special classes under expert care. Special sight-saving classrooms are provided in which these students perform their difficult visual tasks. Since their eyes are unable to function normally, the best possible conditions should be provided such pupils to compensate for their impaired vision. (See Fig. 10-52.)

Surround. Because many critical visual tasks are encountered, classroom brightness ratios should approach unity. (See Table 10-11.) Light distribution from windows and luminaires should be planned in combination with room and furniture surface finishes with this in mind. It is particularly important to have high-reflectance ceilings (80–85%), walls (50–60%), desk tops (35–50%), floors (15–30%), and chalkboards.

Chalkboards occupy a large portion of the surround, often covering most of three walls. They are located at a critical glare angle (0 to 20 degrees above the horizontal line of sight) and frequently at present they are of dark gray slate or other low-reflectance material. (See Fig. 10-53.)

For effective classroom operation the visibility of material on chalkboards, particularly on those at the front of the room, should be good. Almost always supplementary lighting is desirable because of the poor legibility of many types of handwriting and the difficulty of maintaining good contrast between the chalk and the board.

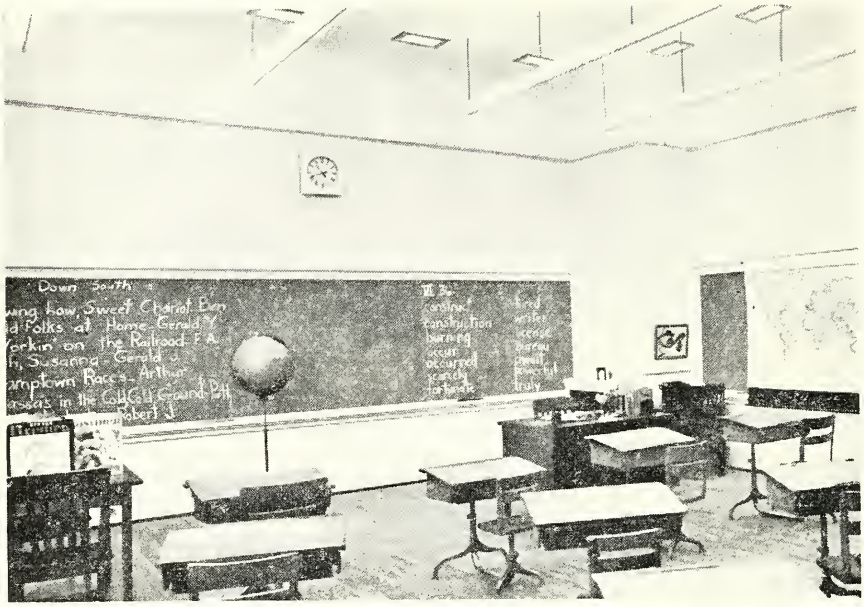


FIG. 10-52. A sight-saving classroom.

Table 10-10. Recommended Illumination Levels for Classrooms and Other School Areas

AREA	FOOTCANDLES MAINTAINED IN SERVICE
Classrooms, including study halls, libraries, shops, lecture rooms, laboratories, etc	30
Sight-saving classrooms, drafting rooms, and sewing rooms	50
Gymnasiums and swimming pools	20
Auditoriums, cafeterias, and similar rooms not used for study	10
Reception rooms, locker rooms, washrooms, stairways, and corridors containing lockers	10
Corridors and storerooms	5

Table 10-11. Recommended Brightness-Ratio Range Limits for Classrooms and Other School Areas

AREAS	RECOMMENDED BRIGHTNESS RATIO RANGE LIMITS IN NORMAL FIELD OF VIEW
Task and immediate background such as desk top, wall, etc	1 to 3— 3 to 1
Task and more remote parts of room	1 to 10—10 to 1
Light source (luminaire or sky) and adjacent ceiling or wall	1 to 20—20 to 1
In no case should the ratio be combined to suggest the acceptability of a range greater than	1 to 30—30 to 1

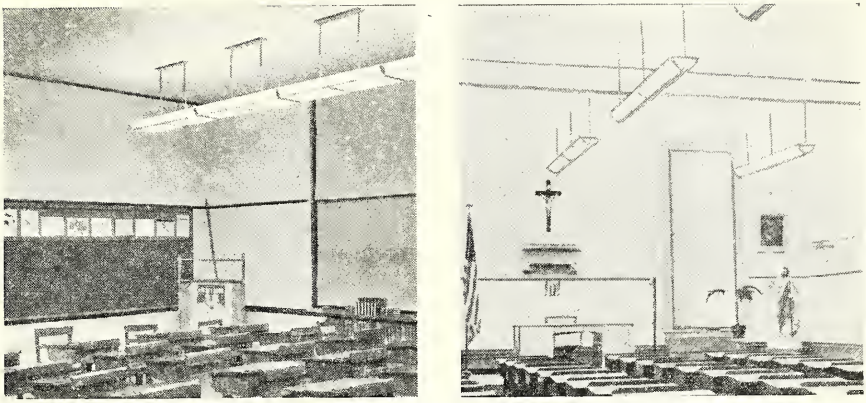


FIG. 10-53. Typical chalkboard installations in classrooms: standard slate (left); high-reflectance (right).

Equipment for the illumination of chalkboards should be located above and in front of the top edge of the boards in such a manner that specular reflections from the boards will not strike pupils' eyes. The most satisfactory location for equipment with a high degree of control is at the ceiling, mounted at a horizontal distance approximately three-quarters of the vertical distance from the center of the board to the ceiling. Equipment of the diffusing type may be mounted much closer to the board, but also preferably at the ceiling.

Maintenance of Classroom Lighting

Classroom design and decoration should be planned for maintenance simplicity as well as for good initial characteristics. In particular, provision should be made for regular cleaning of lamps, luminaires, and room surfaces in order to maintain the highest possible illumination level.

Because adequate maintenance schedules have not yet been generally adopted in schools, a low maintenance factor should be used in design calculations, unless it is known that a regular schedule will be adhered to.

Design Standards

There is considerable standardization in classroom size, room height, seating arrangement, hours of occupancy per pupil, visual tasks, and surroundings. Illumination and brightness recommendations given in Tables 10-10, 10-11, and 10-13 are universally applicable. Higher levels would provide better conditions but are not at this time considered to be economically feasible for the average installation.

The ratios given in Table 10-11 can be maintained by many types of equipment and with many spacing arrangements. The average classroom is 20 to 26 feet wide and 26 to 35 feet long, with a 10- to 12-foot ceiling. Two rows of three overhead luminaires is the most common arrangement. Continuous rows of surface or suspension-mounted, fluorescent-lamp luminaires have met with approval. In most cases these should be arranged parallel to the line of sight. Table 10-12 and Fig. 10-54 describe the most common layouts.

To maintain brightness ratios within the recommended range with incandescent lamps, it is usually necessary to use indirect or semi-indirect luminaires. The brightness of the luminous indirect type often may be made to match that of the ceiling, but the coefficient of utilization of the semi-indirect type usually is greater. Fluorescent lamps permit the use of a semidirect fixture type as well as of a semi-indirect type; troffers and other direct-lighting luminaires can meet the 20-to-1 brightness ratio standard only when wall, ceiling, floor, and furniture surfaces are of high reflectance and are well maintained. The brightness limits shown in Table 10-13 should be used as a guide in the choice of luminaires.

Table 10-12. Maintained Average Illumination Level Provided by a Variety of Installations in a Typical 23 by 32-Foot Classroom Laid Out as Shown in Fig. 10-54*

TYPE OF LIGHTING	LAMP DATA†				LUMINAIRE EFFICIENCY§	WATTS PER SQ FT‖	FOOTCANDLE RANGE¶	ROOM PLAN (Fig. 10-54)
	No.	Watts and Bulb	Lamp Lumens	Type‡				
Opaque or luminous Indirect	6	1,000, PS-52	21,500	I	70–80	8.2	33–41	1a
	6	750, PS-52	15,500	I	70–80	6.1	24–30	1b
90%–100% up	8	750, PS-52	15,500	I	70–80	8.2	32–40	2a
10%–0% down	12	500, PS-40	9,950	I	70–80	8.2	31–39	3a
	56	40, T-12	2,100	F	70–80	3.6	30–38	4a
	30	100, T-17	4,000	F	70–80	4.7	31–39	5a
	84	40, T-12	2,100	F	70–80	5.5	45–56	5b
	40	100, T-17	4,000	F	70–80	6.3	41–51	6a
Semi-indirect	12	500, PS-40	9,950	I	70–80	8.2	34–49	3a
60%–90% up	56	40, T-12	2,100	F	70–80	3.6	33–48	4a
40%–10% down	30	100, T-17	4,000	F	70–80	4.7	34–49	5a
General	48	40, T-12	2,100	F	65–75	3.1	33–43	4b
Diffusing	42	40, T-12	2,100	F	65–75	2.7	29–38	5c
40%–60% up	72	40, T-12	2,100	F	65–75	4.7	50–66	5d
60%–40% down	48	40, T-17	2,100	F	65–75	3.5	33–43	6b
Semidirect	42	40, T-12	2,100	F	60–70	2.7	31–43	5c
10%–40% up	48	40, T-17	2,100	F	60–70	3.5	35–48	6b
90%–60% down	60	40, T-12	2,100	F	60–70	3.9	44–61	7a
Direct	60	40, T-12	2,100	F	60–70	3.9	52–64	7a
0%–10% up	40	40, T-12	2,100	F	60–70	2.6	35–43	8a
100%–90% down	64	40, T-17	2,100	F	60–70	4.7	55–68	8b

* *Recommended Practice of School Lighting*, Illuminating Engineering Society, New York.

† Other types or sizes of lamps in similar equipment may be used, the footcandle result being proportional to the total lumens of the lamps.

‡ I = Incandescent. F = Fluorescent.

§ Assumed over-all efficiency of the luminaire in per cent.

‖ Including watts consumed by control equipment with fluorescent lamps.

¶ The footcandle value within this range will vary, depending on the efficiency of the luminaire within the amounts indicated for that characteristic and on the light distribution within the range described for the type of lighting. Illumination values also will be different for other maintenance factors, room sizes, ceiling heights, ceiling reflectances, and wall reflectances. Values used are: maintenance factor = 70 per cent; ceiling height = 12 feet; ceiling reflectance = 75 per cent; wall reflectance = 40 per cent.

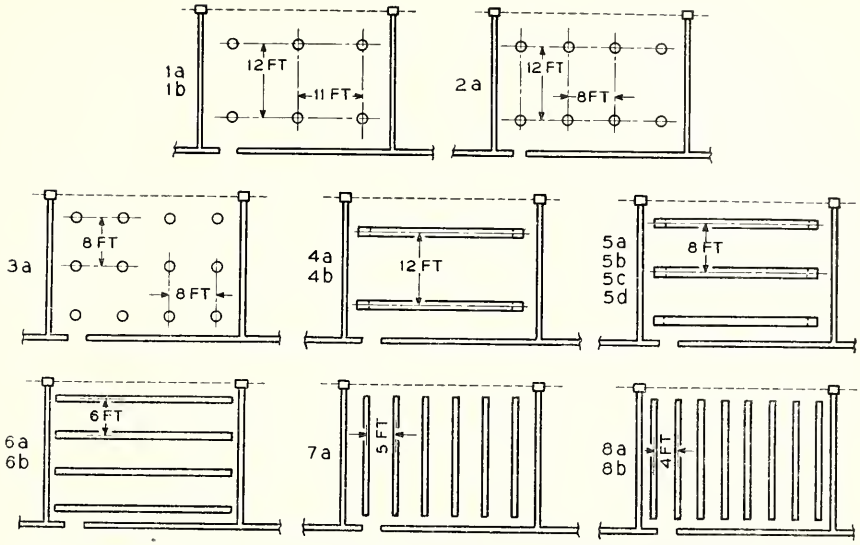


FIG. 10-54. Typical general lighting layouts for a 23-foot by 32-foot classroom. Detailed data on applicable lamps and luminaires and on related illumination levels are given in Table 10-12.

Lecture Rooms

Two levels of illumination are quite desirable in lecture rooms, provided supplementary illumination is provided for the lecture table or teacher's rostrum. This permits the use of contrast when attention to the speaker or his demonstrations is of primary importance, and a high level of general lighting for quizzes and taking notes.

Libraries and Reading Rooms

Local lighting often is used in these rooms, especially when the student is seated along long tables for reading. Assuming recommended levels of illumination are provided, and proper brightness ratio maintained, either localized-general or general lighting may be satisfactory. (See Fig. 10-55.)

Table 10-13. Recommended Maximum Zonal Brightness Limits for Classroom Luminaires

ZONE	MAXIMUM BRIGHTNESS LIMITS*
Vertical to 45 degrees	1,000 footlamberts
45 to 60 degrees	450 "
60 degrees to horizontal	225 "

* If the area involved is small, brightness values up to twice those shown may be acceptable when *all* interior surfaces have a high reflectance mat finish.

Those who advocate the localized-general combination feel that it is more economical (assuming large areas devoted to bookcases and racks), that it is helpful psychologically because of the tendency to concentrate attention, and that it provides the simplest way of providing the recommended lighting levels. Advocates of general lighting point out that general lighting is usually cheaper to install, and that any type of local lighting subject to individual control may work against the desires or comfort of an adjacent student.

Wall cases or stacks should be illuminated separately, preferably with a luminaire designed to distribute light adequately both vertically and laterally.

Drafting Rooms (See Office Lighting page 10-55.)

Art Rooms

The recommended general illumination level may be supplemented by means of lighting equipment such as spotlights or projector lamps designed and installed to increase the visibility of models and other such material from the back of the room. Many instructors prefer electric lighting for this purpose because its color and the shadows it casts are the same throughout the day. Since north skylight is preferred, electrical illumination should blend well with it. Daylight incandescent and fluorescent lamps frequently are used.

Sewing Rooms

Sewing room practices vary appreciably in different school systems, and it is difficult to establish uniform standards for all. Because of the common use of dark materials, and the minute size of the detail to be seen, very high illumination levels are recommended. These can best be provided by installing luminaires to supplement the general lighting. Each machine and work table should be furnished with supplementary lighting.



FIG. 10-55. Typical school library and reading room.

Laboratories and Shops

The work shops of the average school system are in most cases designed to simulate industrial shops. Therefore, it is recommended that the lighting of all such rooms follow industrial practice. (See Fig. 10-56 and the discussion of Industrial Lighting, page 10-94.)

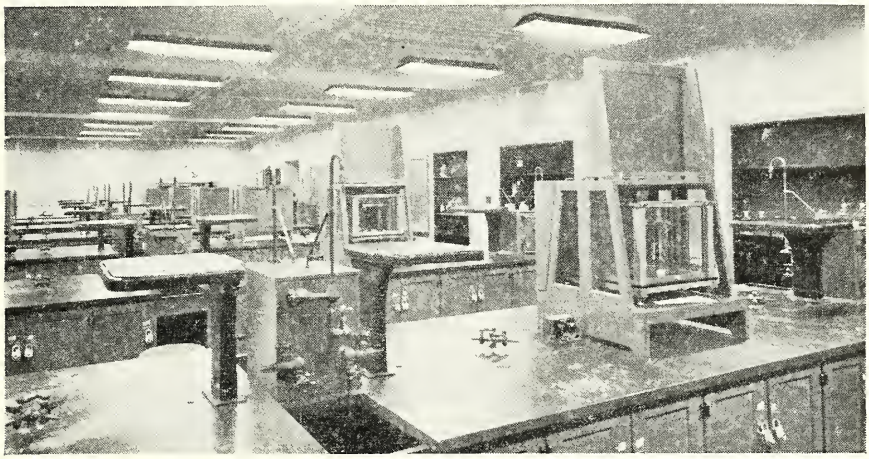


FIG. 10-56. Industrial type, fluorescent-lamp luminaires installed in a school chemistry laboratory.

Cafeterias and Restaurants

The highest illumination levels in cafeterias and restaurants should be found in the kitchen, at the serving counters, and at the cashier's desk. In the eating area the illumination should assist in creating a cheerful, comfortable atmosphere. A relatively low illumination suffices if the rooms are used only for eating, since no difficult visual tasks are involved. If the rooms are used also as study halls, it is recommended that the luminaire and the layout be planned for two levels, one for eating and the other for study.

Auditoriums

School-auditorium lighting should be flexible. Often the room is used both as an auditorium and as a study hall. A level of at least 10 footcandles is recommended for assembly purposes and the classroom level of 30 footcandles for lecture and study periods.

Corridors, Stairways, and Locker Rooms

The recommended illumination level is 10 footcandles. Where locker installations are fixed, luminaires should be located so as to illuminate the face and interiors of lockers. Frequently a corridor-lighting installation does not adequately light stair landings, in which case additional luminaires should be installed for each landing. Care should be taken in locating stairway luminaires so that they illuminate the edges and faces of all steps.



FIG. 10-57. A dormitory room lighted for study hour.

Dormitory Rooms

Except in special schools (as in military schools, perhaps) there should be few differences between the lighting goals for dormitories and those for similar rooms in the home (bedrooms and living rooms). (See pages 10-36 and 10–42.) Most of the differences are associated with lack of decoration, uniformity, ease of cleaning, and similar factors—few of which deal directly with the quantity and quality of illumination. (See Fig. 10-57.) Military dormitories may tend more toward general illumination from ceiling fixtures rather than localized illumination from portable lamps. Under such conditions, general-office lighting standards should be followed. (See page 10-52.)

The lighting of dormitory rooms should satisfy two dissimilar requirements:

1. Contribute to a comfortable and attractive relaxation atmosphere.
2. Provide the 30-footcandle classroom illumination level recommended for study purposes.

Portable lamps at each desk and lounge chair may be adequate if they distribute enough light throughout a room to bring brightness ratios within the classroom limits.

COMMERCIAL AND PUBLIC BUILDINGS

Almost any structure except a residence might fall into the category, "commercial and public buildings," but the term usually is construed by illuminating engineers to mean theaters, banks, libraries, and museums, and the public portions of office buildings, hotels, churches, concert halls, hospitals, and similar large areas of high turnover and intermittent occupancy. Modern lighting design is co-ordinated with the architectural theme in public buildings more often than in other structures. The characteristic public-occupancy areas of such buildings include lobbies, auditoriums, work and service areas, corridors, stairways, and so forth.

Office Buildings

The lobby of an office building usually is at street level. The simplest type is a wide hallway giving access to the elevators or stair wells. More elaborate lobbies may be used as an exhibit hall by groups occupying the building. Many have shops located along the sides. (See Fig. 10-58.)

From a visual standpoint, decorative lighting that produces 10 footcandles in a lobby usually may be considered sufficient for safe passage of pedestrians, provided there is auxiliary lighting at directory boards, and directional signs, and adjacent to the elevators and stair wells as a safety measure. However, since most office buildings have their maximum traffic in the daytime, 5 footcandles may be found insufficient to provide satis-

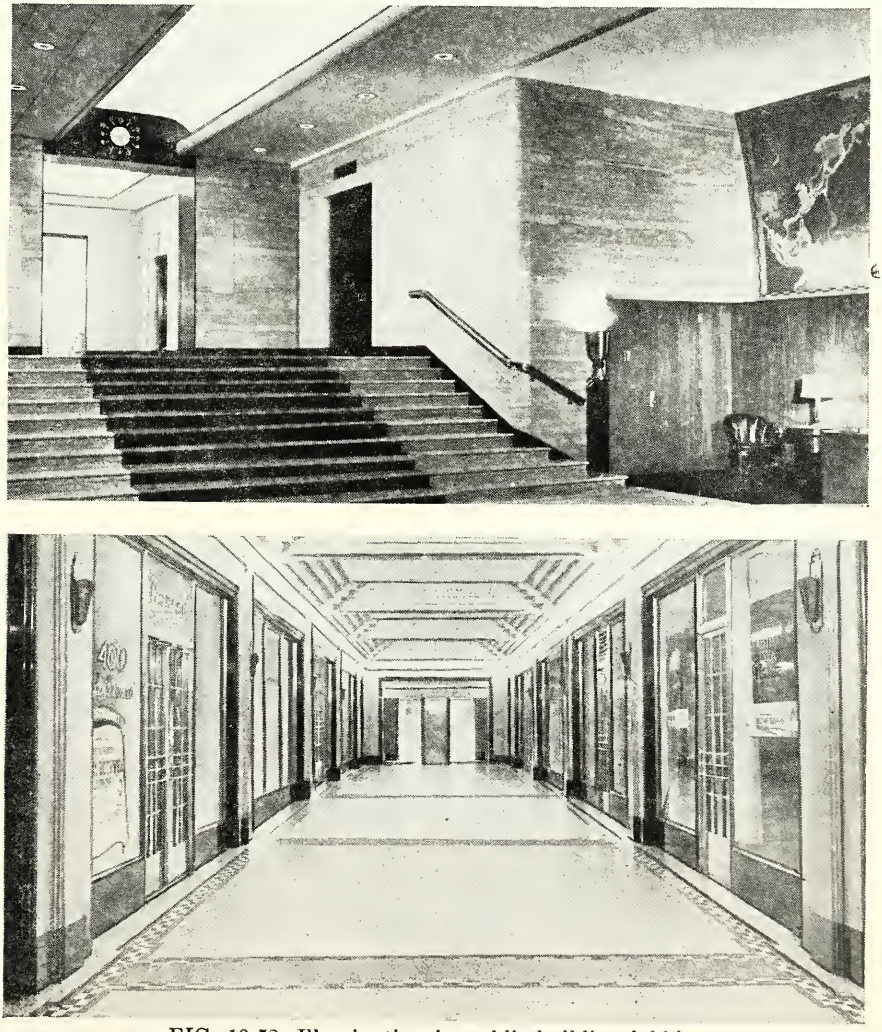


FIG. 10-58. Illumination in public-building lobbies.

factory visual adaptation as the visitor steps into the lobby from out-of-doors (from an illumination level approaching 10,000 footcandles in direct sunlight). This necessity for adaptation combined with the advertising value of higher levels and brighter surroundings has led many building designers to provide higher levels of illumination (20 footcandles).

In hallways and corridors of ordinary ceiling height (less than 30 feet) luminaires should be spaced not more than 20 feet apart. No branch corridor should be without a luminaire. A luminaire located at a main corridor junction will serve two branches not more than 10 feet deep. For safety in such locations, at least two lamps should be used in each luminaire.

No entrance to an elevator or a stair well should be more than 10 feet from a luminaire. The recommended average illumination level for elevators, and stair wells, is 10 footcandles, assuming high-reflectance surfaces. The lumieaire and layout should provide such a uniform level that the maximum value at any place in the room is not greater than three times the minimum.

Theaters

Theater-lighting design begins outdoors with the combination decorative facade with display cases which identifies the entrance. Part of this entrance is the marquee. Sources in the marquee often provide a high illumination level around the box office. This level is reduced along the traffic lane into the threater so that the theatergoer's eyes may become adapted gradually to the lower levels inside.

Theater lobbies are passageways between the street and the foyer. An illumination level of 20 footcandles is desirable in lobbies. The walls and ceilings should have a high brightness (up to 50 footlamberts). At signs announcing current or coming attractions 20 to 40 footcandles should be provided by local lighting for accent. The luminaires may be ceiling-mounted spotlights, or lamps and reflectors attached to the signboard.

Foyers are areas where traffic is distributed into the auditorium. An illumination level of 10 footcandles is recommended. This is sufficient for recognition of acquaintances, for safe movement, and to arouse interest in the decoration, and yet permits quick adaptation to the lower auditorium level. In larger theaters, a lounge or promenade may separate the lobby and the foyer. The illumination level in such an area should fall between those of the lobby and the foyer.

In the *auditorium* proper, three rules should be observed: (1) brightnesses should be low; (2) sources should be placed out of the normal field of view from any seat in the house; (3) in motion-picture theaters the light should be so controlled that a minimum falls upon the screen. (See Fig. 10-59.) Stray light reduces contrasts in the screen image. Brightness up to 10 footlamberts may be used between the acts. Luminaires should be located as far outside the field of view as practicable. See also Section 14.

To relieve brightness contrasts between the screen and its immediate surround and thus contribute to eye comfort, a low brightness of approxi-

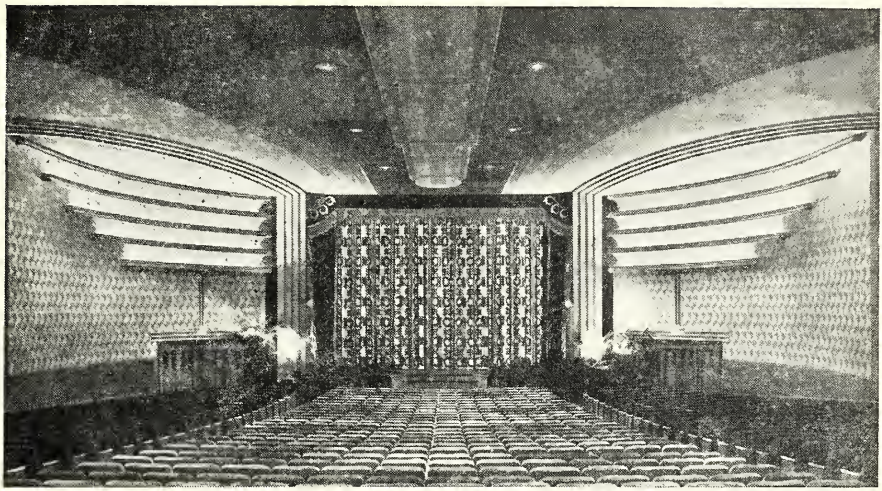


FIG. 10-59. A community theater auditorium.

mately 1 footlambert on the surfaces adjacent to the screen is recommended. In lighting such surfaces, the source must be concealed and so directed that no light spills on the screen to reduce picture clarity. Any luminaire type may be used (coves, shielded downlights, or masked projectors) that will border the picture screen with surfaces of about one-tenth screen brightness.

For motion-picture theaters, illumination levels can be graded from $\frac{1}{2}$ footcandle at the rear of the auditorium to $\frac{1}{10}$ footcandle at the front. Some provision should be made to supply higher levels for emergencies, for cleaning, and at the end of the final presentation.

Few theaters have sufficient illumination for program reading. In community theaters where the auditorium may be used for other than motion-picture projection additional lighting may be necessary. Theaters used solely for stage plays need not have over-all low-intensity lighting. A minimum of 5 footcandles should be provided everywhere for the reading of programs during intermissions. Individually controlled local luminaires on the backs of seats have been used successfully in some theaters to provide light for reading programs and for locating lost objects.

Aisle lights located under the outside row of seats can provide useful illumination without introducing high brightnesses in the field of view of the seated audience.

Some use is made of carpets impregnated with fluorescent materials which become luminous when irradiated by means of ultraviolet sources.

Theater Stages

The stage provides the most interesting lighting problem in the theater. Even those theaters designed exclusively for motion pictures occasionally may accommodate stage shows for charity, for community rallies, and so forth.

Stage lighting equipment includes border lights, footlights, spotlights, floodlights, and cyclorama floodlights. (See Fig. 10-60.)

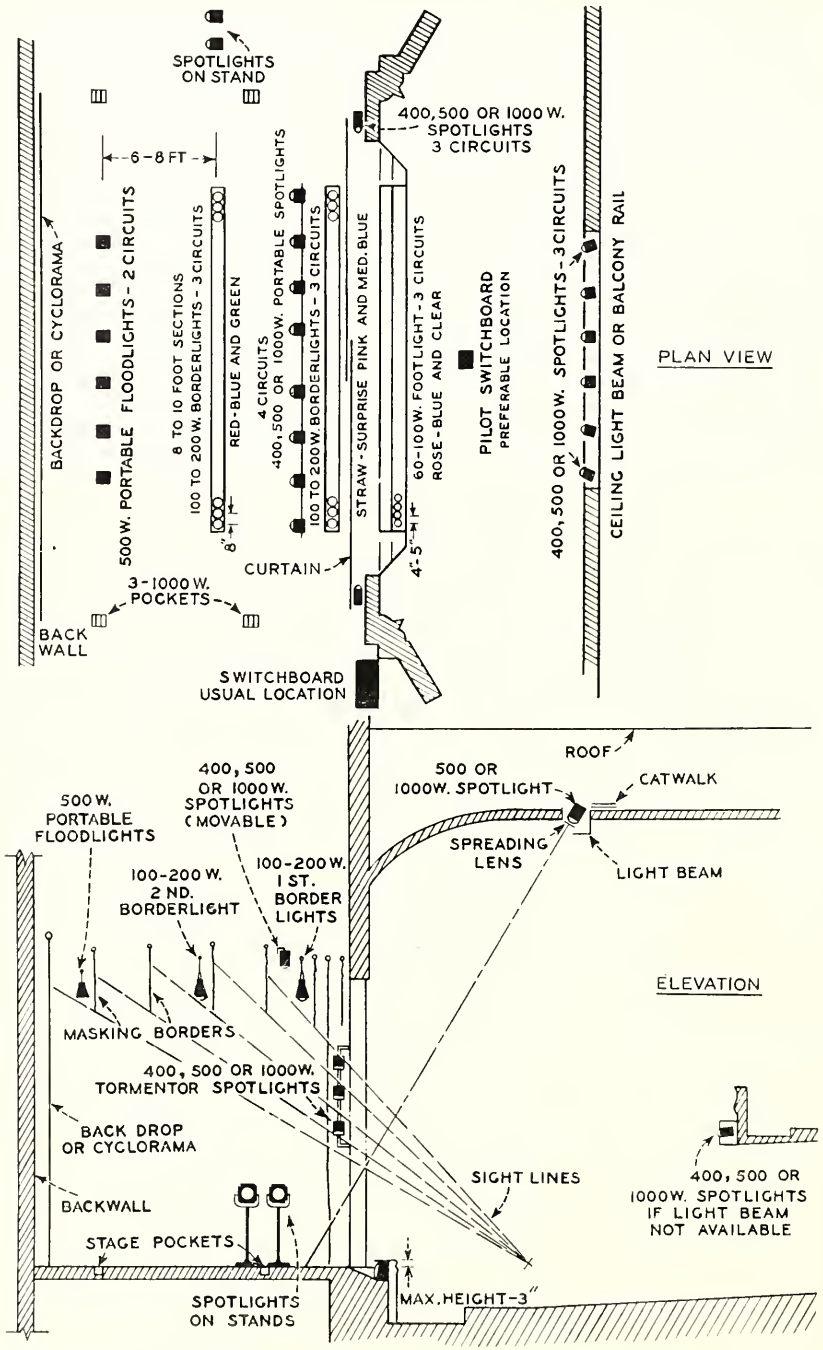


FIG. 10-60. Typical plan and elevation for a large stage.

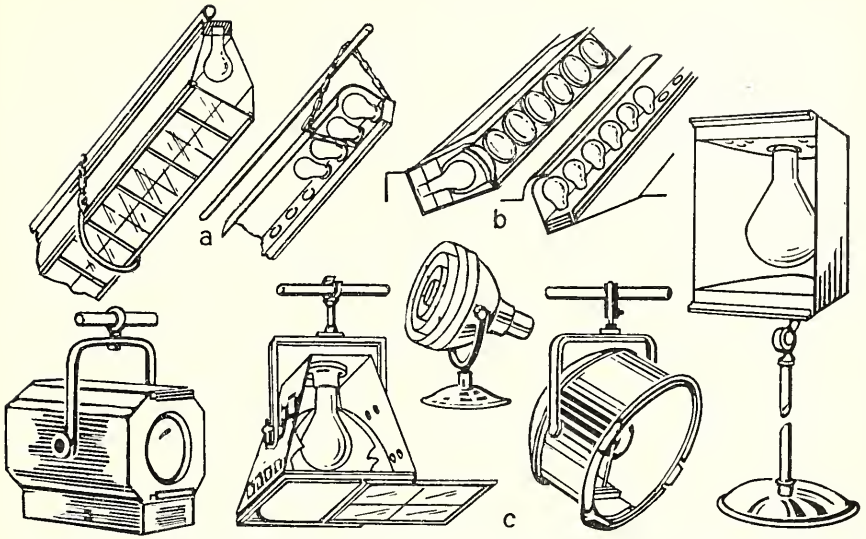


FIG. 10-61. Stage-lighting equipment; a. border lights; b. footlights; c. spotlights and flood lights.

Border lights provide general illumination for the stage. Depending on stage depth, one to four rows are hung parallel to the curtain, with the first border as close behind the curtain as feasible. All border lights are mounted so that they may be adjusted vertically, since otherwise they might interfere with the use or placement of various stage sets, or not be in a position to supply the proper light distribution. Border lights include bare lamps in long troughs, individual lamps and reflectors grouped together as troughs, and individual, separately operated spotlights. (See Fig. 10-61a.) In any case color flexibility is a requirement. Bare lamps with different filter coatings; individual reflectors with glass roundels or gelatin filters; and spotlights with gelatin filters are the primary color mediums. Usually three to five colors are used. All those of one color are wired for simultaneous control. They should be so spaced that uniform coverage may be provided with any combination. Borders are electrically controlled so that each circuit may be dimmed. The incandescent lamps used include 40- to 60-watt bare lamps on 5- or 6-inch centers, 100- to 200-watt lamps in individual reflectors on 9- to 12-inch centers, and 250- to 500-watt lamps in spotlights.

Footlights are located in front of the curtain line and usually consist of one row of sectionalized disappearing units. (See Fig. 10-61b.) Their purpose is to soften and eliminate harsh shadows which tend to appear on faces lighted only from above, and to provide illumination when the stage action requires the actors to move "downstage" near and beyond the curtain line. Like border lights, they may be bare lamps in troughs or in individual reflectors. Usually they are wired in several circuits, and are dimmer controlled.

Spotlights and floodlights located in the wings adjacent to the border lights or in the auditorium proper provide accent lighting. (See Fig. 10-61c.) Many stage designers use spotlights almost exclusively to produce the required high levels, using border lights and footlights to provide a more uniform level than may be obtained with the imperfect spotlight overlap. A spotlight is a luminaire in which a reflector behind the lamp or sometimes a lens in front of it, or both, is used to focus the output of the lamp in a narrow beam. Incandescent lamps with ratings between 250 and 2,000 watts and carbon arcs are used in spotlights. By comparison, floodlights have a wide beam. Lamps of any type and size are used, depending on the equipment size, with the control depending on a reflector behind the lamp and on the housing edge.

Theater Lighting-Control Systems

Theater-lighting circuits for both the stage and the auditorium often are equipped with dimming devices. The lighting should be expressive and versatile, achieved through dimmer blending of various color circuits and by regulating the quantity of light delivered to a particular area. When this blending or regulation is to be achieved as a part of the lighting sequence, the gradations of light should be produced smoothly and accurately.

Dimmer control of auditorium lights facilitiates eye-accommodation. Even relatively low auditorium levels may cause momentary blinding glare when the lights are switched on immediately after either a dark stage setting or a motion picture has been viewed.

Most dimmers regulate light output by varying lamp current. Individual preheat-starting (hot) cathode fluorescent lamps cannot be dimmed conveniently in this manner over a wide brightness range, since the arc extinguishes with a small voltage drop. However, the output of incandescent lamps and instant-starting cylindrical (cold) cathode lamps may be controlled smoothly over a very wide range. The most common dimmer is the resistance type. When not loaded beyond their rated capacity, resistance dimmers can handle smoothly the circuit to be controlled and dissipate the heat produced by its operation. Circular dimmers are designed for loads as high as 4,000 watts. When resistance dimmers have too little load for their rated capacity, complete blackout of the circuit is not possible. This condition is corrected by the addition of dummy loads or by the use of other types of dimmers, particularly variable autotransformer dimmers or electronic tube-reactor dimmers.

Churches

Lighting for churches should be co-ordinated with the church service, and suited to the architectural design. (See Fig. 10-62.) Soft well-diffused illumination is recommended. High levels attract the attention of the worshipper to the altar or pulpit at certain points in the services. The amount of illumination provided at the pews should be keyed to the amount of reading expected of the congregation, some of whom may have

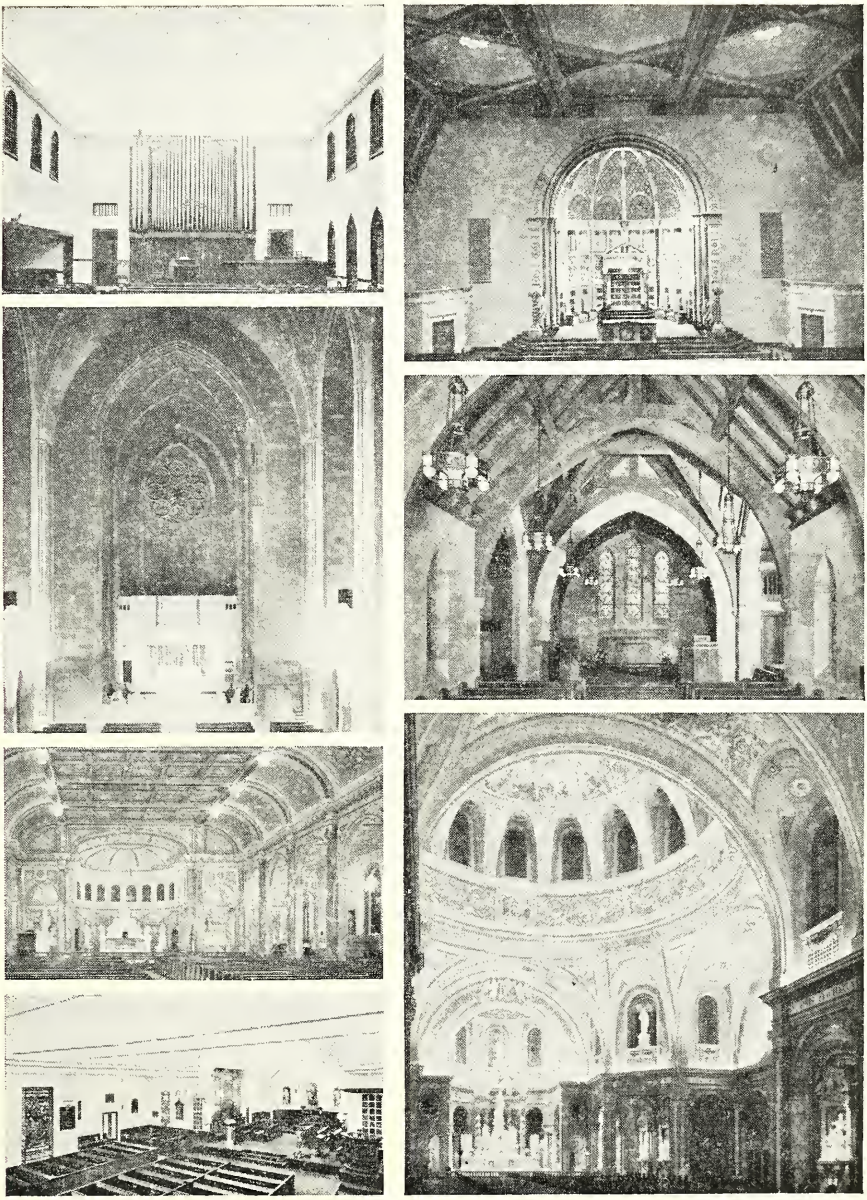


FIG. 10-62. Typical church-lighting installations.

impaired vision. If the illumination requirements vary during the service, provision should be made for switching or dimming as required.

Church tradition and architecture are appreciably older than electrical lighting. Therefore, where a traditional plan is desired, electrical illumination should supplement the natural illumination unobtrusively.

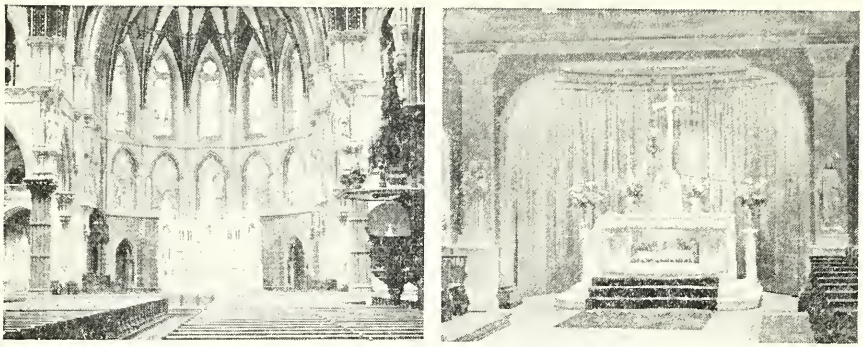


FIG. 10-63. Illumination of typical altars.

For example, the Gothic church with high vaulted ceilings has depended in the past upon directional daylighting from great windows along the walls. The resulting shadows and dimly lighted vaults are responsible for the majestic beauty of the Gothic style. Therefore, artificial lighting for Gothic structures can be supplied best by luminaires of the direct type, supplemented if necessary by indirect and local lighting to minimize contrasts or provide illumination levels suitable for reading.

Other types of interiors call for a completely indirect lighting system. Concealed flush downlighting has been used successfully also.

Directional spotlights, recessed-lens-controlled luminaires, pinhole downlights, or coves and troughs may be concealed from view in a variety of ways.

Indirect lighting which more readily results in diffuse and soft lighting is used in many churches of the congregational auditorium type, and in many with Greek or Roman temple plans.

The altar sanctuary requires local lighting. (See Fig. 10-63.) Emphasis lighting can be directed to any area or object by equipment concealed in niches or behind ceiling beams. Glare protection for the congregation results from the angle at which the light is directed. Local lighting on pulpits and lecterns is almost always necessary. Conversely, general rather than local lighting, is recommended for the choir loft because of the difficulty of locating and adjusting local luminaires, and the possibility of resultant glare for the congregation.

Banks

Most banks have a main floor area, divided between the public portion and the service cages. For the public portions, many types of equipment are in common use. (See Fig. 10-64.) Sufficient illumination should be provided for the depositors' transactions.

When the architectural style makes it difficult to provide adequate general illumination, local lighting at writing tables and on the tellers' side of the tellers' cages also is recommended, since critical seeing tasks are performed at these places and a low level of illumination may result in errors. Care should be taken to maintain low brightness ratios by means of high-reflectance surfaces and low-brightness luminaires.

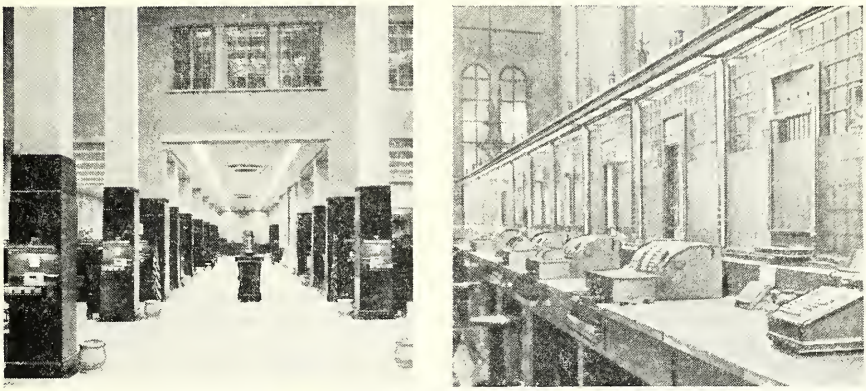


FIG. 10-64. Views of good lighting installations for banks.

Museums and Art Galleries

Museums and art galleries are primarily places for objects to be displayed for study and appreciation. The illumination on vertical and oblique planes may be of greater importance than that on the horizontal.

Color, line, proportion, and perspective, all of which are affected by light, are particularly important in displays. Well-planned illumination is based on a consideration of the artists' mediums, techniques, and objectives.

General design guidance is provided in Table 10-14. It is doubtful if an art gallery can be designed to give satisfactory natural lighting during much of the year and the future may see such structures designed for electrical illumination only.

Hospitals

An *operating room* presents the most difficult lighting problem in a hospital. Illumination in excess of 1,000 footcandles is desirable on the operating table; color is important; shadows and glare must be minimized; there should be no appreciable addition of heat at or around the operating table.

A variety of installation plans have been developed. Recessed ceiling reflectors, controlled by prismatic glass plates, may be arranged in a rectangular or circular pattern around the table. With such an arrangement, doctors and nurses are not likely to obscure the light to an extent that will handicap the operating surgeon. Suspended clusters of luminaires directing light at the table from many angles provide similar diffusion. Another common method is to suspend over the table a large area reflector that controls the light from a single lamp. Beam spread can be varied by focusing. Flexible mounting permits aiming of the beam. (See Fig. 10-65.) Regardless of the plan or luminaire selected, the over-all room brightness pattern is important. A surgeon concentrates on a relatively small area but at times his visual field will include parts of the room. Therefore, the brightness of all areas in the room should be maintained uniform by high-reflectance surfaces and general illumination. The brightness should approach as closely as possible that at the operating table.

Table 10-14. Lighting Design Guide for Art Gallery and Museum Displays

TYPE	MATERIAL	PRINCIPAL PLANE AND SURFACE	ILLUMINATION LEVEL ON PRINCIPAL PLANE (foot-candles)	REMARKS
Oil paintings* Individual or group Unframed	Canvas Wood Silk Velvet	Vertical Dull	30 50 30 50–100	Annoying reflected images are likely to be formed of high-brightness, poorly placed luminaires
Framed	Canvas	"	30	
Unframed	Wood	Vertical Glossy	50	To avoid reflections should not be displayed on opposing walls
Single	Canvas	Vertical Glossy	30–50	Mask completely from other objects; light as individual piece
Water Colors* Group Framed and Unframed		Vertical Glossy Dull	20	
Murals* Individual Unframed	Plaster	Vertical Horizontal Dull Glossy	20–50	Display to avoid reflections
Etchings, engravings, mezzotints* Group Framed Unframed	Paper	Vertical Dull Glossy	20–30	Display to avoid reflections
Ceramics † Group	China, etc.	Inclined Dull Glossy Semiglossy	20	Generally shown in illuminated display cases
Sculptures † Free-standing Individual	Marble Terra-cotta Plaster Wood Light bronze Dark bronze Red copper Green copper Brass Gold Silver Ivory Wax	Vertical Dull Glossy Semiglossy	30–100 30–50 30–100 20–100 200 500 300 500 200 100 100 30–50 30–50	See paper by H. L. Logan, "Modeling with Light," *Illum. Eng.*, February 1941

* Single plane involved. † Three dimensions involved.

The desired color usually is obtained by means of glass filters; other glass filters are used to absorb heat. It is preferable to provide operating rooms with a separate emergency lighting system or to have facilities to operate the regular system from an independent power supply in emergencies.

Wards and *private rooms* have one problem in common usually not found in home bedrooms; most patients lie awake for long periods facing the ceiling. Both direct-lighting and high-brightness patterns from indirect luminaires should be avoided. The best type of luminaire is that with a wide upward distribution. It should not be mounted too close to the ceiling and should have a brightness in the patient's field of view approximately equal to that of the ceiling. Special wall-mounted types with a downward component for reading are available.

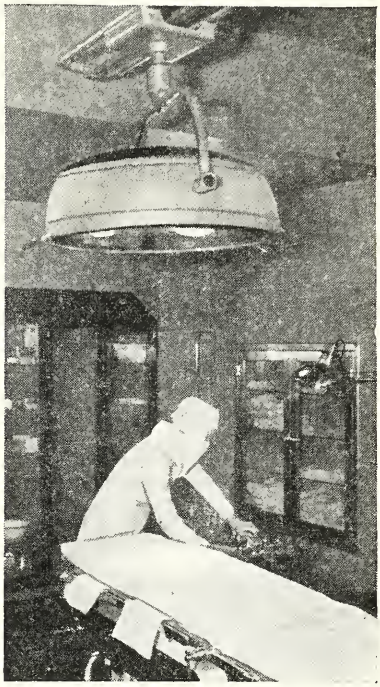


FIG. 10-65. A hospital operating room showing the operating table luminaire and the small spot on which its beam may be focused.

Hotels

There is no hotel lighting problem not covered by recommendations for other public buildings and for the home.

For the *guest rooms* one point deserves special emphasis—the universal nature of the room. Often it is living room, bedroom, library, and dining room combined and sometimes a merchandising area as well. Therefore, a flexible lighting plan is recommended. General lighting may be provided by a single central luminaire to be controlled by a switch near the entrance. Local lighting should be added for atmosphere and to provide adequate illumination for individual tasks (reading, writing, etc.).

Hotel *bathrooms* require at least as much attention as a similar room in a home; the unfamiliar surroundings increase the importance of good lighting for shaving. (See page 10-43.)

Hotel *auditoriums* differ in two respects from other auditoriums:

1. They have flat floors so that they may be converted into ballrooms.
2. Though a stage often is located at one end this may not be the focal point of attention.

A symmetrical decorative and flexible lighting layout is recommended.

Hotel *lobbies* are reception halls and are used as lounge rooms as well. Adequate illumination should be provided for those who wish to read and write. Usually, portable lamps are practical. They emphasize the home-

like character of the hotel and are flexible and easily coordinated with any decorative scheme.

INDUSTRIAL LIGHTING

In 1915 the Illuminating Engineering Society prepared and issued a *Code of Lighting Factories, Mills and Other Work Places.* According to the procedure of the American Standards Association, revisions of the Code were made in 1921 and in 1930. The 1942 *American Recommended Practice of Industrial Lighting,* which is condensed here, is a development of the earlier codes.

Illumination is an environment factor that affects every industrial establishment. The advantages of good illumination to employees and management are many.

Production and Quality Control

Under good illumination it is possible to see an object of much smaller size than is discernible under poor illumination. Continuous quality control throughout the manufacturing process, made possible by good illumination, permits early discovery and rejection of defective parts prior to further processing or final inspection.

Floor space utilization. A uniform level of general lighting such as shown in Fig. 10-66 makes possible the most efficient arrangement of machinery and conveyors and better utilization of floor space. Manufacturers have learned that in many cases more work can be achieved with less floor space when the work flows in straight lines through assembly or inspection sections. Good general lighting facilitates the arrangement of straight production lines.

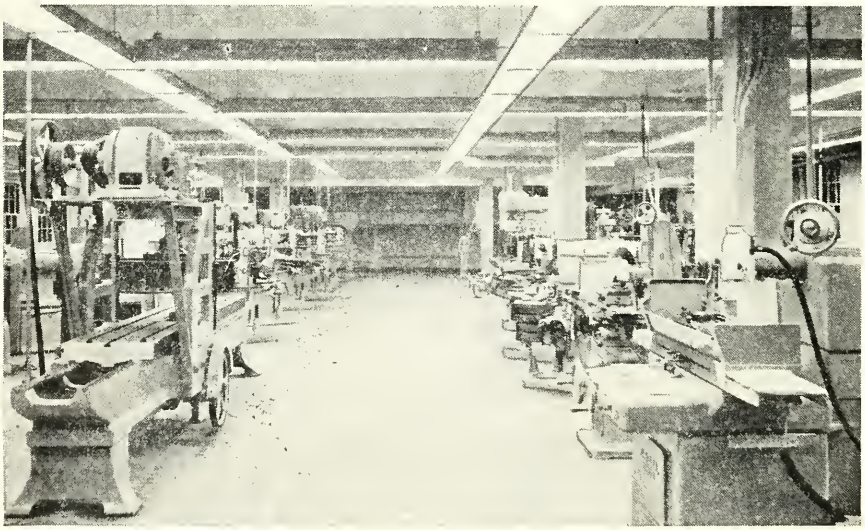


FIG. 10-66. A uniform level of general lighting permits the optimum utilization of floor space and increases the flexibility of the production line plan in this shop.

Cleanliness. Industry has found that cleanliness pays. Poor illumination makes it difficult to see into corners or under machinery and these dark areas collect dirt and waste that would otherwise be cleaned out. Where dirt can be seen it is more likely to be removed. In a well-lighted plant dingy areas do not exist and much more sanitary conditions prevail.

Light and safety. Engineering for safe plant operation consists essentially of preparing a safe working environment. The environment should be designed to match and to compensate for the limitations of human capability. However, as revealed by an analysis of accidents and their causes, this is but one phase of the safety problem. Most personal injury accidents involve a combination of personal and mechanical causes. The chain of circumstances or series of causes which has led a workman to a potential injury frequently can be broken only if he can see quickly and accurately the causes and act to prevent the accident.

Factors of Good Illumination

There are many factors involved in good illumination. These can be summed up under the headings *quality*, which includes the direction and diffusion of light, its color, etc., and *quantity*. Separately and in conjunction they have significant effects on the ability to see easily, accurately, and quickly.

Quality of illumination: light diffusion and distribution. Some directional and shadow effects are desirable in general illumination for accentuating the depth and form of solid objects, but harsh shadows should be avoided. (See Fig. 10-67.) Shadows are softer and less pronounced when many wide-distribution diffusing luminaires are used. Alternate light and dark areas in strong contrast are not desirable because the adaptation of an observer's eye to first one and then the other of the two brightnesses is fatiguing. For this reason, purely local lighting restricted to a small work area is unsatisfactory; there should be sufficient general illumination throughout the room. High (30 to 60 per cent) reflectance surfaces serve several purposes. They reflect light toward the working areas, they reduce contrasts between walls, ceilings, windows, and luminaires. Machinery with a high-reflectance finish reflects light to otherwise shadowed areas.

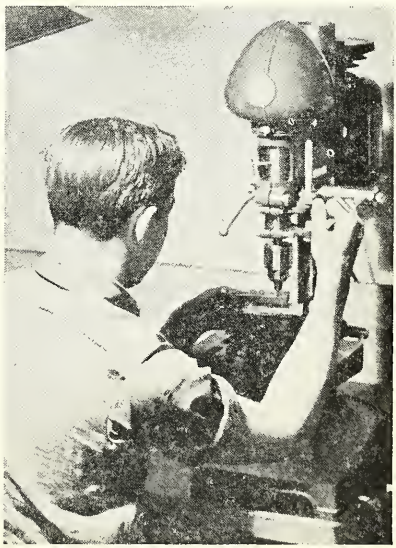


FIG. 10-67. Uncontrolled shadows usually interfere with vision. However, in some cases shadows may be utilized also to simplify seeing tasks.

Clearly defined shadows, without excessive contrast, simplify the seeing task in certain types of operations such as engraving on polished surfaces, scribing on metal, and some textile inspection. (See Fig. 10-67.) Controlled shadows may be provided by supplementary luminaires.

Many of the seeing tasks in industry are on vertical or nearly vertical surfaces. Hence the amount and the distribution of light on vertical surfaces often are important. (See Fig. 10-68.)

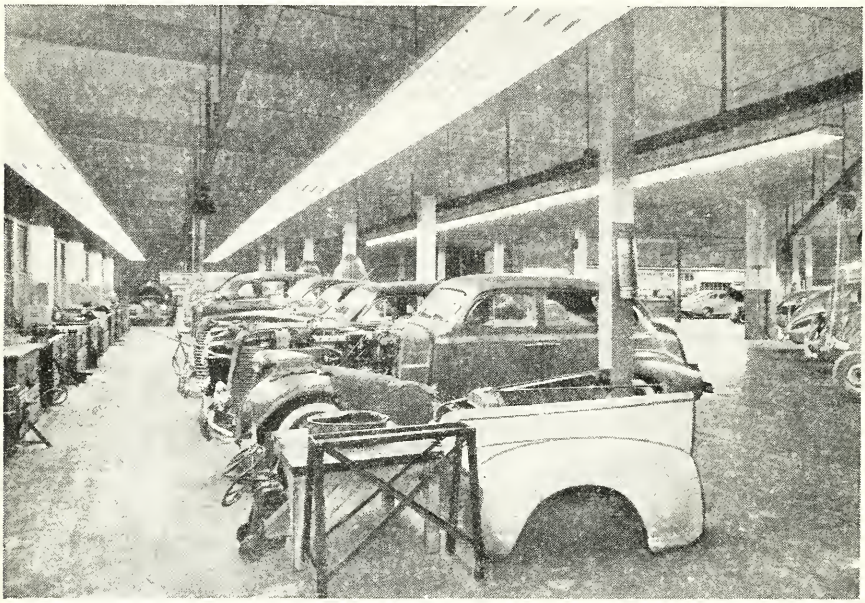


FIG. 10-68. In many industrial areas the visual problems occur on vertical as well as horizontal planes. In such cases uniform illumination should be provided on the vertical.

Quality of illumination: color. With equal illumination (footcandles) variations in color quality of light have little or no effect upon the visibility of tasks that do not involve color discrimination. However, in certain industries color discrimination is important and in these the spectral quality of the light on the work may be critical. Some manufacturers paint stationary and moving parts of machines different colors to increase contrast and prevent accidents.

Quantity of illumination: recommended levels. The illumination recommended for an installation depends upon the seeing task. The degree of accuracy required and the size of detail to be observed, the color and reflectance of task and surround materially affect the brightness distribution required for optimum seeing. As illumination on a task is increased, its brightness and the ease, speed, and accuracy with which it can be accomplished usually are increased.

Surface brightness measurements may be made with a brightness meter (see Section 5). Brightness may be computed by multiplying the illumination by the reflectance of the surface.

Most of the recommended illumination levels in Appendix Table A-1 apply to the average room. If it is desired to determine the level produced by an existing installation, the measurement procedure outlined in Section 5 should be followed.

The majority of the recommended values of illumination shown in Table A-1 refer to the general lighting measured on a horizontal plane 30 inches above the floor. In some cases where an illumination level of more than 50 footcandles is necessary, it may be obtained by a combination of general lighting plus supplementary lighting at the point of work.

The Illuminating Engineering Society in recent years has been studying the illumination needs of specific industries. If a more detailed discussion of the lighting specifications for a specific process is desired than it has been possible to include in the handbook, the reports referred to should be consulted.

To ensure that a given illumination will be maintained (even where conditions are favorable) it is necessary to design the system to give initially at least 25 per cent more light than the required minimum. In locations where the dirt will collect rapidly and where adequate maintenance is not provided, the initial value should be at least 50 per cent above the minimum requirement.

Where safety goggles are worn, the light reaching the eye is likely to be materially reduced and the general level of illumination should, therefore, be increased accordingly in these locations.

General Lighting in Industry

Modern industrial lighting practice is to provide a uniform illumination level throughout every work area. This is called general lighting. The general-lighting level should be uniform so that light will be available, when needed, at any point. This is particularly desirable for interiors where the production layout may be changed. If the general lighting has been designed for uniform illumination, tables, machines, and conveyors often may be moved without necessitating a change in lighting installation.

The purpose of a general-lighting system where there is also supplementary lighting is to keep the brightness ratios between the task and the surround within a range that is comfortable to the eyes (not over 10 to 1) in order to provide sufficient light for safety and to illuminate secondary visual tasks.

Luminaire Spacing and Layout

The lumen method of design described in Section 8 is used to design general-lighting installations intended to provide reasonably uniform illumination over a given area. The footcandle level calculated by this method is the average for the entire area. The level in a well-designed system at any specific point near the center of the room may vary 5 per cent even in an empty room with no equipment or other obstructions.

The variation may be as great as 30 per cent if points next to the walls are considered, unless special attention is given these areas.

Layout suggestions. The conventional arrangements of electrical outlets for lighting (one, two, or four per bay) have been adequate for a wide range of footcandles because of the many incandescent-filament lamps available in the 150- to 1,500-watt range with outputs of from 2,600 to 33,000 lumens each. By comparison, the fluorescent-lamp range, encompassing only a few ratings between 15 and 100 watts with outputs of 495 to 4,400 lumens each, is limited. To obtain a lumen output per fluorescent luminaire comparable with that of a 500- or 1,000-watt, incandescent-lamp luminaire, it is necessary to use many lamps.

Fluorescent lamps, by virtue of their tubular form, suggest new layout and installation methods: continuous rows of lamps and "troffer" systems. Since the lamp lengths and ballasts are different for each of the fluorescent lamp sizes, these lamps are not interchangeable. However, future increases in illumination may be provided for by a wiring layout that will accommodate added luminaires or rows of luminaires to co-ordinate with the original installation. (See Fig. 10-69.) It is possible, also, in some two-lamp luminaires to add a third lamp of the same size, with an increase in illumination of approximately 50 per cent. Where such luminaires are spaced closely, or in continuous rows, the two extra lamps in adjacent luminaires can be served from a two-lamp ballast located in one of them. Two-lamp industrial units with reflectors punched for lampholders for a third lamp are used. This potential capacity may serve several useful purposes. By adding the third lamp almost 50 per cent increase in illumination may be made available over a small area for especially difficult visual tasks, or throughout the installation for a general increase in illumination. Illumination levels from a general-lighting system are low near walls when not

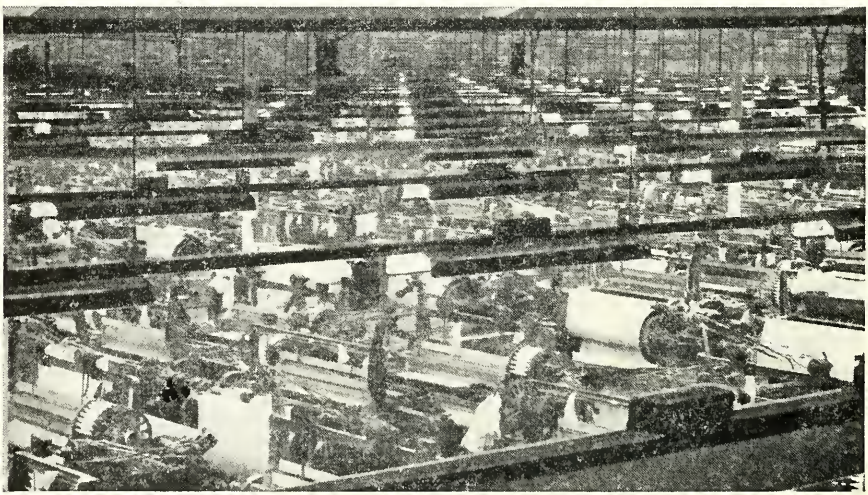


FIG. 10-69. This luminaire installation is arranged to minimize the complexity and expense of future increases in illumination. Spacing plan permits addition of units without disturbing existing installation.

supplemented by natural light from windows. The latter cannot be depended upon at all times. It is possible to compensate for the daily and seasonal variations in natural illumination by using the third lamp in outside end rows and in the two end reflectors of the rows between. In large installations this can be accomplished by having all the luminaires in outside bays fitted with a third lamp. In incandescent systems, lamps of higher wattage than in the center of the room should be used in the outer bays.

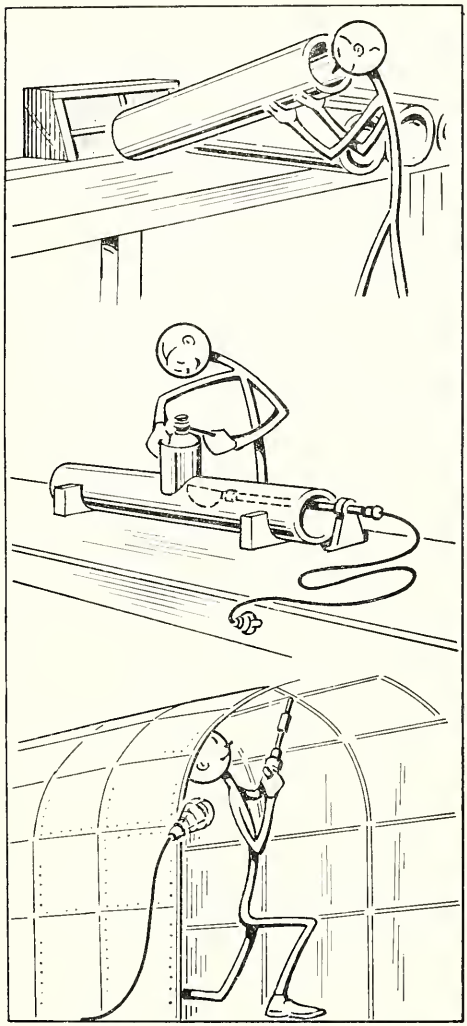
Mounting height. For practical purposes the average illumination level produced by general-lighting installations of spread distribution luminaires in large areas (room index > 5) is independent of luminaire mounting height. In small areas the average varies in proportion to the coefficient of utilization, not inversely with the square of the distance from luminaires to illuminated plane. Spacing between luminaires usually should not greatly exceed their mounting height.

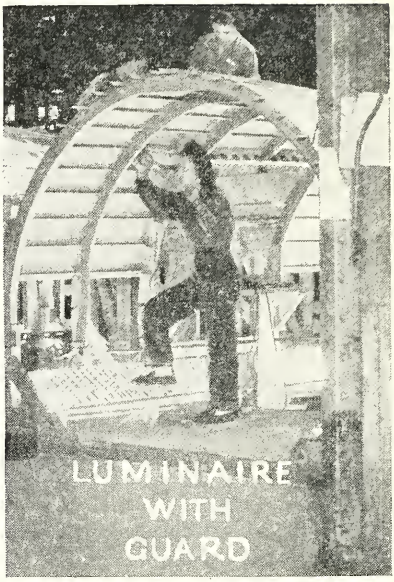
Supplementary Lighting in Industry

Extremely difficult seeing tasks require illumination levels which are not always easily or economically obtained by standard general-lighting methods. To solve such problems supplementary luminaires often are used to provide high levels for small or restricted areas. Also, they are used to provide a certain brightness or color, or to permit special aiming or positioning of light sources to avoid shadows caused by workmen or machinery. A reasonably comfortable interior usually results when the general-illumination level is at least one-tenth that of the supplementary level. Employees using their eyes for critical visual tasks glance away from their work at frequent intervals for momentary relaxation. If the brightness contrast between task and surround is too great, instead of being rested, the eyes are fatigued.

Supplementary luminaires. Two types of supplementary equipment will take care of almost all requirements: (1) Small, concentrating projectors augment the general lighting on a seeing task and provide directional quality. (2) Large-area, low-brightness diffuse sources may provide either general lighting for small areas or "plus" lighting for a more difficult seeing task such as inspection. (See Fig. 10-70.) All supplementary luminaires and projector lamps should be shielded, louvered, or mounted so as to minimize the possibility of glare. Where adjustable fluorescent luminaires are used, they should be of the two-lamp type to minimize stroboscopic effects.

Portable luminaires. Portable equipment can be used to good advantage in airplane hangars and garages and wherever internal surfaces must be viewed. A typical unit consists of five angle-reflector luminaires mounted on a portable rack with outlets for electrical tools. Two-hundred-watt, inside-frosted incandescent lamps are recommended. A "trouble light" consisting of 50- or 100-watt rough-service lamps in a guarded socket attached to an extension cord often is provided for internal inspection. Similar devices have been developed for fluorescent lamps.





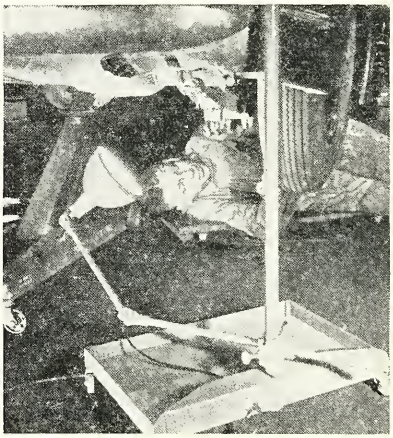


FIG. 10-70. Typical supplementary- and portable-lighting equipment designs. Portable-lighting equipment often is useful for repair work and for increasing illumination on surfaces which are inaccessible and not reached by general lighting.

Hazardous locations. Vapor-proof, explosion-proof, and dust-tight uminaires each are designed for a specific type of location where either corrosive vapor, inflammable gases, or explosive dusts are likely to be encountered from such processes as oil refining, paint and varnish making, or lacquer spraying. (See Fig. 10-71.) Special equipment such as this usually is mandatory also in locations with moisture-laden atmospheres such as steam processing, engine rooms, and shower baths. The National Electrical Code requires the use of these special types of luminaires in cer-

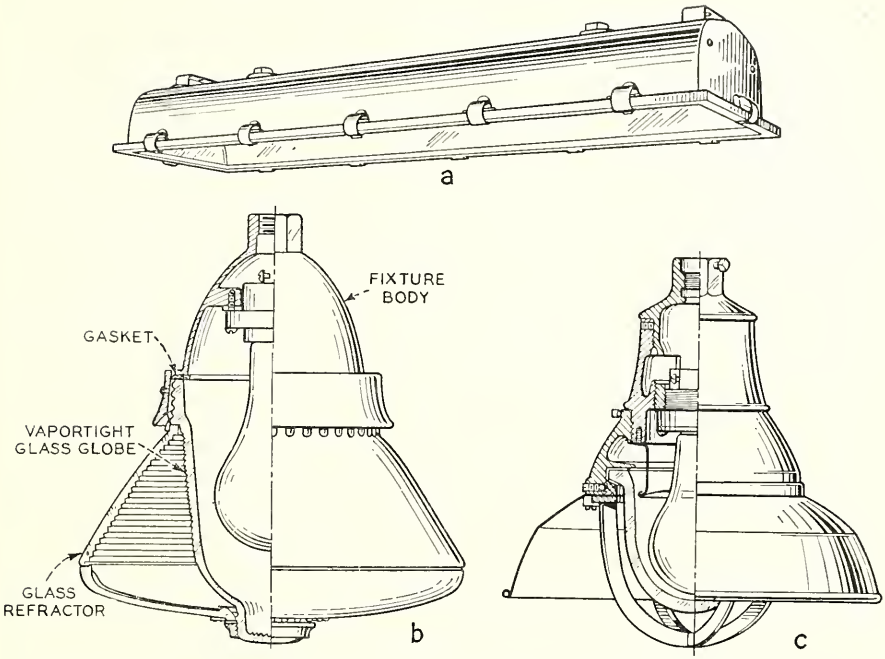


FIG. 10-71. Luminaires for hazardous locations: a. dust-tight; b. vapor-proof; c. explosion-proof.

tain areas. Both angle and symmetrical types of reflectors in the 75- to 500-watt size range are used.

Lighting for Industrial Inspection

In most production processes there are one or more inspection operations that involve checking some characteristic of a material or product against a previously established specification or standard. Although inspection or checking sometimes is accomplished by the use of devices requiring little visual effort or skill on the part of an operator, acceptance or rejection often depends on the accuracy of the visual observations of a skilled inspector. Usually, because of the importance of the inspector's decisions in such cases, it is worth while in planning a lighting installation to treat an inspection area as a special problem. The following examples suggest ways in which a variety of typical inspection problems have been solved.

Highly polished surfaces. Chrome or tin plate, aluminum sheet, and other specular surfaces frequently are inspected visually to detect scratches, dents, bare spots, and other flaws. It has been found that an inspector can locate such flaws when he views an image of a low-brightness luminaire in the polished surface. The image should be at least as large as the area to be inspected and its brightness should be not more than 400 footlamberts. (Surround brightness should be not less than 1/10 image brightness.) The area to be inspected should be so screened that images of other sources, windows, machinery, or personnel are not in the inspector's field of view.

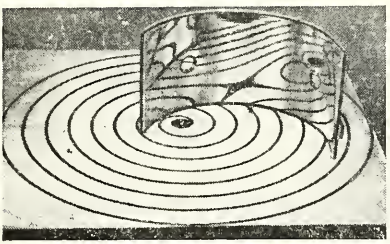


FIG. 10-72. Flaws such as grind marks in highly polished surfaces form distorted images of regular patterns superimposed on the low-brightness surface of the inspection table or inspection luminaire. They may be detected easily by this method.

Opaque bands of uniform width equally spaced in parallel lines, rectangular grids, or concentric circles are of assistance in detecting surface contour irregularities. These are revealed by a distortion of the image pattern which in some cases may be noticeable only when the inspector moves his head. (See Fig. 10-72.)

Printers' imposing stones, type composition cases, and metals used for scribing present similar seeing problems which may be solved in this manner.

Refractive flaws in transparent materials may be detected by viewing the image of such a source or the source itself through the material.

The following rules of thumb are applicable to the inspection of plate glass:

1. The glass should be viewed against a combination of light and dark areas.

2. The light source should have a brightness of less than 1,800 footlamberts (4 candles per square inch).

3. The light source preferably should be rectangular in shape with a width of 5 to 6 inches and a length of 24 to 30 inches. With luminaires of this size the width of the dark spaces between should be of the order of 2 to 3 feet.

Trough-shaped luminaires are located approximately 6 feet behind the support for the glass plate. The supporting framework for the glass plate should be raised or lowered to bring the glass area between the eyes of the inspector and one or more of the luminaires.

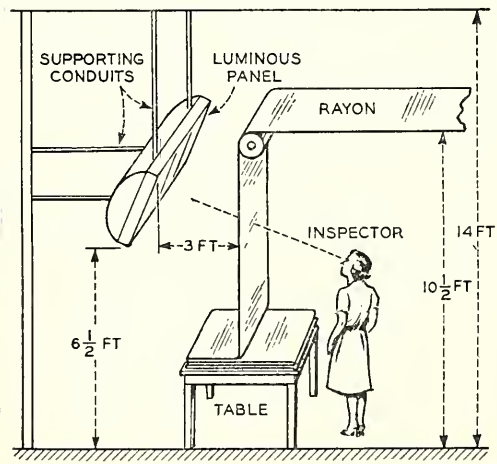


FIG. 10-73. Low-brightness source for silhouette inspection of translucent materials such as fabrics, glass, plastics, paper, liquids, etc.

Open-weave fabrics and other translucent materials. The location and removal of any defects in open-weave fabrics previous to the final finishing process is accomplished best by observing the defects in silhouette against a large-area, uniformly low-brightness panel such as shown in Fig. 10-73. The brightness of the panel should be sufficient to show up defects. It should not exceed 400 foot lamberts. The surround brightness should not be less than 1/10 that of the panel. For the best

silhouette vision the illumination on the cloth from the observer side times the reflectance of the cloth should be not more than one-tenth the brightness transmitted by the cloth.

Light transmitted through translucent materials such as glass, paper, plastics, and liquids also may reveal certain kinds of faults, foreign material, and defects. Large luminous panels can be built in conveyor lines over which, or past which, the material flows. The illumination level required varies with the task. A panel brightness of the order of 100 footlamberts often is adequate. Bubbles, blisters, cracks, chips, and whorls may be revealed as highlights or distortions caused by refraction when transparent materials such as glass jars, bottles, bulbs, clear plastics, etc., are seen moving before a large-area, low-brightness panel. Alternate dark and luminous backgrounds or black strips laid on a luminous background aid in locating and identifying defects.

To detect small fire cracks and bubbles in glass jars and the pin-point bubbles caused by foreign material in carbonated beverages, a narrow beam source is recommended. The mirror action of these defects reveals their presence.

A modification is the arrangement employed for the inspection of inner tubes for air leaks. The partially inflated tube suspended from an overhead conveyor is passed through a trough filled with water under the surface of which there are light sources on each side of the inspector's stand. Any air bubbles coming from the tube are made visible by the light they reflect.

Polarized illumination. The detection of internal strains in glass, mounted lenses, lamp bulbs, radio tubes, transparent plastics, etc., may be facilitated by transmitted polarized light. The nonuniform spectral transmittance of strained areas causes the formation of color fringes that are visible to an inspector. With transparent models of structures and machine parts, it is possible to analyze strains under operating conditions.

Nonspecular materials. Surface flaws, irregularities in surface shape, pit marks, scratches, and cracks in nonspecular or mat materials are most easily seen by lighting which strikes the surface obliquely in such a manner that nonuniform surface contours cast shadows. Wrinkles in roofing materials are revealed by small shadows which the wrinkles cast when the sheet is illuminated by a narrow light beam incident at a grazing angle.

Directional light also has been found useful for the inspection of sandpaper and Venetian blinds. (See Fig. 14-6.) The light may be specular for inspecting mat surfaces, but should be diffused at the source for examining polished or shiny materials.

Minute details and high precision. Careful inspection of very small objects may be greatly simplified by viewing their magnified images. For production work the magnified image may be projected on a screen. Because the projected silhouette is many times the actual size of the object, any irregular shapes or improper spacings can be detected readily. Similar devices are employed for the inspection of machine parts where accurate dimensions and contours are essential. One typical device now in common use projects an enlarged silhouette of the teeth of a gear on a profile chart.

The meshing of these production gears with a perfectly cut standard is examined on the chart.

Color control and classification. Many manufacturing operations in the paint, lacquer, enamel, dye, textile, paper, tile, and printing fields include careful color-control procedures. Section 4 includes detailed discussion of these problems.

Moving parts. It is sometimes necessary to inspect and study moving parts while they are operating. This can be done with stroboscopic illumination which can be adjusted to "stop" or "slow up" the motion of constant-speed rotating and reciprocating machinery. Stroboscopic lamps give flashes of light at controllable intervals (frequencies). Their flashing can be so timed that when the flash occurs, an object with rotating or reciprocating motion is always in exactly the same position and appears to stand still.

METAL WORKING

Some very difficult seeing tasks are encountered in metal-working shops. The difficulties are a result of many different causes, including the following:

1. Low-reflectance metal surfaces result in low task brightnesses. The rapid collection of oil and dirt further reduces reflectance and makes good maintenance difficult.
2. Work and machine surfaces are of similar character and reflectance and consequently provide poor contrasts.
3. Specular metal surfaces in the process of fabrication form images of luminous areas in the surround.
4. Much metal-working machinery is bulky, and obstructs the distribution of light flux.
5. Dimensional tolerances often are extremely narrow.

In many industrial processes the seeing task may be greatly facilitated by painting various parts of the working areas, including the machines, in contrasting colors of good reflectance. (See Section 4.)

Lighting for Heavy Industry

The heavy-industry type of metal working is done in foundries, steel and iron mills, and fabrication assembly plants in the manufacture of such products as ships, locomotives, engines, turbines, structural steel, and automobile bodies. This work is carried on in high-bay buildings covering large areas. Materials are moved from place to place by means of traveling cranes. General illumination usually is provided by high-bay luminaires, employing a high output light source such as the incandescent lamp or high-intensity mercury lamp. (See Fig. 10-74 and Fig. 10-75.) Incandescent- and mercury-lamp combinations sometimes are installed on alternate outlets. The illumination from this arrangement is whiter than that of either source alone; radiation from the incandescent alone is yellowish and from

the mercury alone bluish green. Twin reflectors, one for an incandescent and one for a mercury lamp, frequently are mounted side by side in order that the radiation from the two sources will be more uniformly blended.

For mounting heights of 20 feet or less, current practice is to use fluorescent-lamp luminaires. Where possible, when fluorescent-lamp luminaires are used to provide general lighting, they should be installed in rows or rectangular patterns. Such a system is independent of subsequent rearrangement of machines and work areas.

Even with the best general illumination, some supplementary lighting frequently is required. Supplementary luminaires may be fastened to vertical columns, to side walls, or to a machine. (See Fig. 10-76 and Fig. 10-77.)

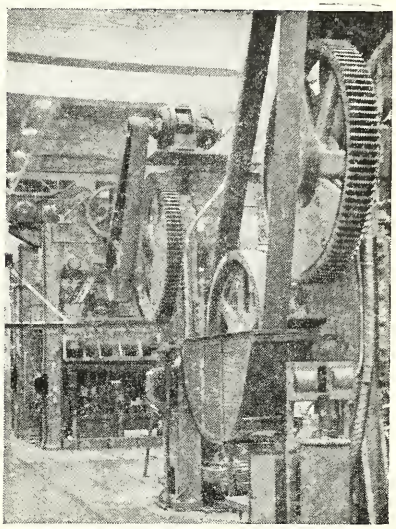


FIG. 10-74. Fifteen-hundred-watt incandescent lamps on 16-foot centers 35 feetabove the floor in this press room provide a level of 30 footcandles.

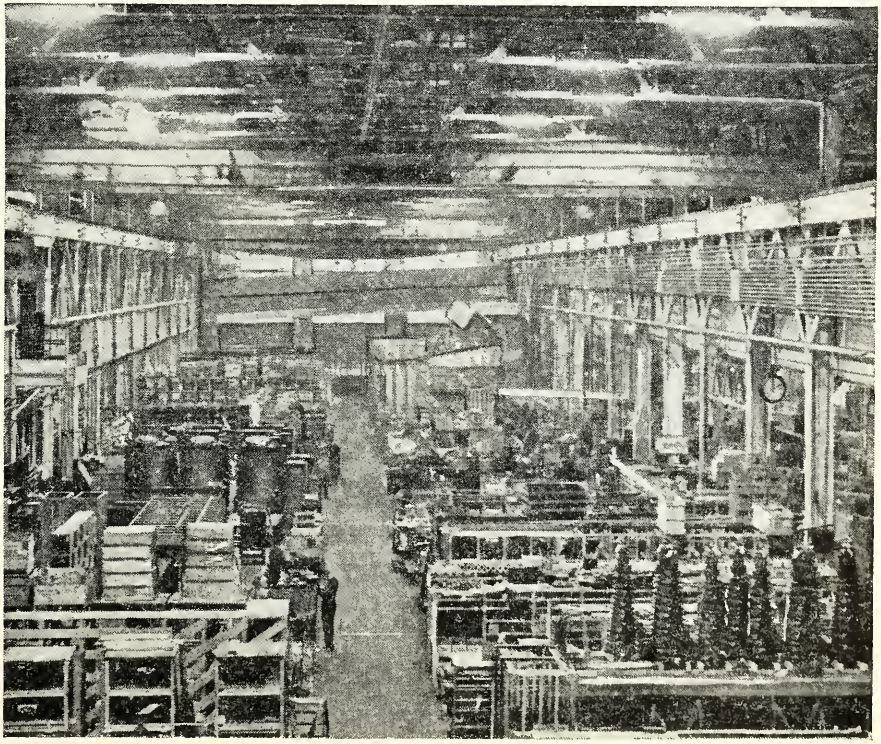


FIG. 10-75. High-bay area lighted with 3-kilowatt mercury lamps in open reflectors.

For areas where manufacturing operations are subject to periodic or frequent changes, several flexible wiring systems have been developed that make possible convenient regrouping of luminaires. One type utilizes raceways from which movable luminaires are suspended. Power is drawn from enclosed copper busbars through sliding contacts.

Disconnect and lowering hangers are available for the mounting of luminaires when, because of height or other local conditions, this type of installation facilitates maintenance. (See the discussion of maintenance, page 10-20.)

Machine tools. Manually operated and automatic machine tools are

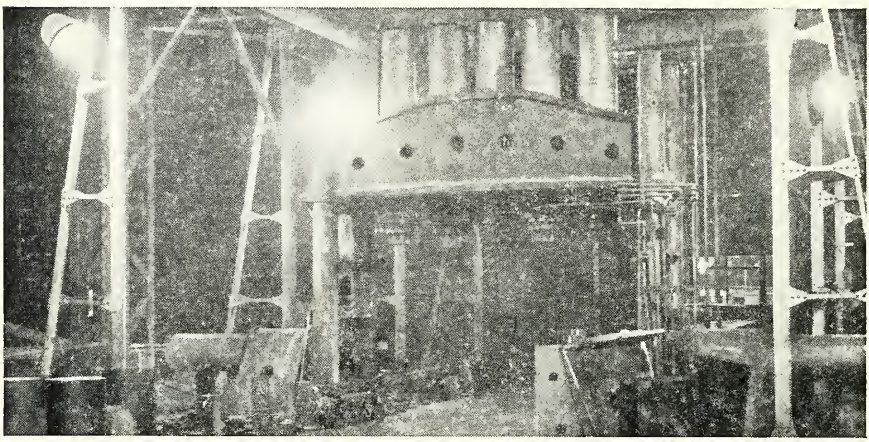


FIG. 10-76 Local lighting of a large press. Four 400-watt mercury lamps in dust-tight angle reflectors provide 40 footcandles on the working plane. They are mounted 15 feet above the bed of the press.

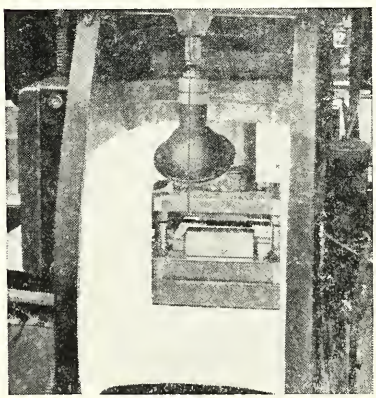


FIG. 10-77. The working plane of this punch press is lighted by an angle reflector locally mounted at the back of the press.

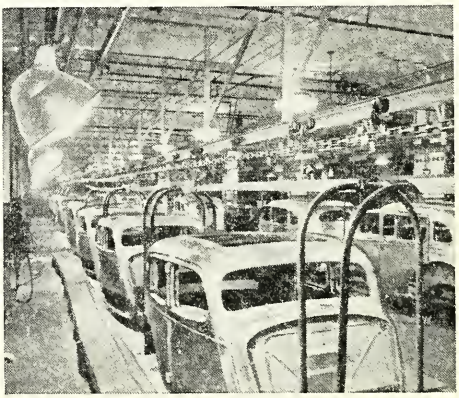


FIG. 10-78. An installation of 400-watt mercury lamps in dust-tight RLM and angle reflectors along the conveyor in an automobile-production line.

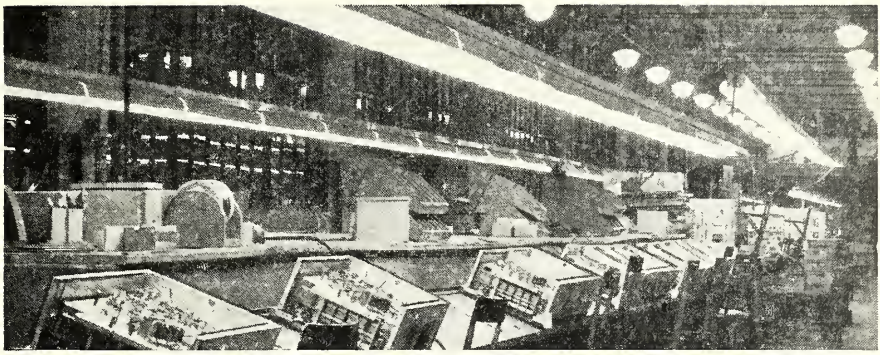


FIG. 10-79. Illumination provided by fluorescent-lamp luminaires over this radio-assembly line supplements the general lighting provided by the incandescent-lamp diffusing globes. Approximately 100 footcandles are provided on the work.

best lighted with extended sources. Lamps in large low-brightness luminaires produce larger highlights in highly polished surfaces than do those in small high-brightness luminaires.

Deep-boring operations frequently require supplementary illumination provided by adjustable luminaires.

Production-line assembly. In production-line assembly each worker must complete his task within a limited time. Often the large number of people concentrated in a given area makes the shadow problem serious. Current practice is to treat such assembly areas as local lighting problems. When most of the seeing tasks are on a vertical plane, or on both vertical and horizontal planes, rows of luminaires mounted slightly behind the worker and at an angle are used. Where the seeing tasks are primarily on the horizontal plane, continuous rows of luminaires are mounted relatively close above the work along the entire length of the line.

Many types of lamps can be used successfully for lighting assembly lines. (See Fig. 10-78 and Fig. 10-79.)

Bench work. Many precision operations require handwork at a bench. Fixed luminaires mounted over a bench usually are satisfactory, but for some tasks adjustable luminaires may offer advantages.

FOUNDRY LIGHTING

The lighting requirements for foundry operations are about the same whether the worker is making nonferrous metal, steel, or gray and malleable iron castings, or whether the foundry is large and highly mechanized or small and designed for job-lot work. Recommended levels of illumination for foundries are given in Appendix Table A-1. Many operations such as molding and core making involve nonspecular-surface seeing tasks. In areas where such work is done, high-output luminaires can be installed high above the floor without introducing glare. Smoke and steam cause maintenance problems that are minimized through the use of the smallest practicable number of easily maintained luminaires.

Core making. The seeing tasks involved in core making are:

1. Inspection of the empty core box for foreign material.
2. Inspection of the core-box sand filling for holes and other flaws.
3. Trimming fins and wire after baking, to finish the cores.

Two types of core boxes are in common use. One is made of metal and the other of wood. Each type presents its own seeing problem. The metal box has a specular finish. A low-brightness luminaire is recommended. The wooden core box usually is painted black or varnished and has about the same reflectance as sand and therefore does not contrast with it.

In designing the localized-general lighting systems recommended for core making, the luminaires are placed with their center line directly over the edge of the bench used by the worker in performing the operation. This minimizes reflected glare and shadows.

Molding area. The sand mold is formed by packing treated sand in a flask about a pattern or it may be assembled entirely from sand cores previously formed and baked. The pattern is withdrawn after packing to form a cavity in the sand. Sand cores are then placed within the mold to complete its preparation. The flask comprises upper and lower halves which, when assembled, form an enclosed cavity into which molten metal is poured.

The seeing tasks involved in forming molds from treated sand are:

1. Inspecting the pattern for foreign material.
2. Setting the pattern in the flask and packing sand around it.
3. Removing the pattern and inspecting the mold for loose sand and for accuracy.
4. Inserting cores; operator must be able to see the core supports.
5. Smoothing mold surfaces, checking core position, and checking clearance between parts.

Where sand is supplied from overhead ducts and conveyors, localized general lighting is recommended. Where there are no overhead obstructions, a general-lighting system should be used.

Charging floor. The weighing and handling of metal for charging furnaces is a simple visual task. General illumination should be provided on the charging floor.

Pouring area. The pourer must see the sprue or pouring basin in the mold in order to direct properly the flow of the metal. The low reflectance of the sand sometimes is offset by placing white parting sand about the opening in order to increase contrast and improve visibility. When weights are used, the opening in the weight indicates the general location of the sprue. A general-lighting system is recommended.

Shake-out area. In the shake-out area, the operator handles flasks and castings. Sometimes, he must also remove the flares and risers from the castings. A general-lighting system is recommended, but if a ventilation hood is employed over the grate, supplementary lighting is required on the grate.

Grinding area. In grinding the operator removes excess metal and fins from castings, grinding to contour, to a mark, or to a gauge. Protective glasses worn by the operators often become fogged. The seeing task is fairly severe. For hand- and swing-grinder operations, a general-lighting system is recommended, for stationary grinders, a combination general-and-supplementary-lighting system. Good practice for stationary grinders is to locate the center line of the luminaires approximately 6 inches from the edge of the wheel on the side toward the operator.

Sand-blasting or cleaning area. Three methods are used for cleaning castings:

1. Sand blasting in a blast room.
2. Sand blasting in a cabinet or on a rotary table.
3. Friction in a tumbling barrel.

The principal visual tasks are:

1. Handling castings.
2. Directing the blast stream (when manual).
3. Inspecting the castings to see that they are clean.

For lighting large sand-blast houses, a general-lighting system is recommended. Luminaires should be located on the outside of the room directing light through protecting glass plates in the ceiling or walls so as to be accessible for maintenance.

Chipping area. The chipper's job is to remove excess metal such as fins from castings. A general-lighting system is recommended.

Inspection area. Inspection tasks are as varied as the multitude of products that pass through the foundry. The inspector must determine if castings are complete, if they have slag holes, or if there are cracks caused by improper cooling, sand holes, cold shuts, and blows, and he must correct surface appearance and correct match. The detection of cracks is the most difficult seeing task.

Some inspection operations are very simple and do not involve fine detail or accurate discrimination. For more precise inspection, light should be well diffused to minimize shadows in cavity and cored molds. The luminaires should be of large area and low brightness and should be located over the inspection bench or area. Either a "light hood" luminaire or a two-directional grid layout of linear luminaires may be used. (See Fig. 10-80.) Deep cavities and tubular areas may require the use of small, shielded portable luminaires.

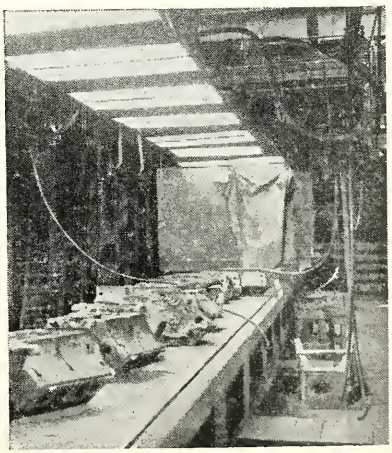


FIG. 10-80. Large-area, low-brightness luminaire installation for foundry chipping and inspection area.

Yard lighting. Narrow-beam, incandescent-lamp reflectors, mounted either on the sides of the buildings or on

fences, poles, or steel towers are used for lighting industrial yards. Any equipment exposed to the weather should be enclosed for protection against moisture and dirt. A mounting height of 30 feet usually is considered a minimum. When very narrow beam projectors are used, careful aiming and overlapping is required to eliminate shadows. Street-lighting reflectors or refractors with widespread light distribution are used also.

TEXTILES

The seeing tasks in the textile field include both simple ones and some of the most severe found in industry. Recent improvements in various kinds of textile machinery and methods have increased its productivity, but at the same time have increased the severity of many visual tasks. For example, in some weaving sheds one weaver now may operate as many as thirty-six looms and it is necessary for him to see quickly and accurately. The lighting requirements are determined by the color, weave, and fineness of the material being fabricated as well as by the specific operation under consideration. Textile operations can be classified into three groups according to the type of fabric involved: (1) cotton, (2) silk and synthetic fabrics, and (3) wool.

Cotton Mill Lighting

Such operations as *opening*, *mixing*, *picking*, *carding*, and *drawing* can be carried out in a satisfactory manner if uniform general illumination of the order of 10 to 15 footcandles is provided. Luminaires for several types of fluorescent and incandescent lamps can be used successfully. (See Fig. 10-81.) The incandescent-lamp type often is used because of its low initial cost.

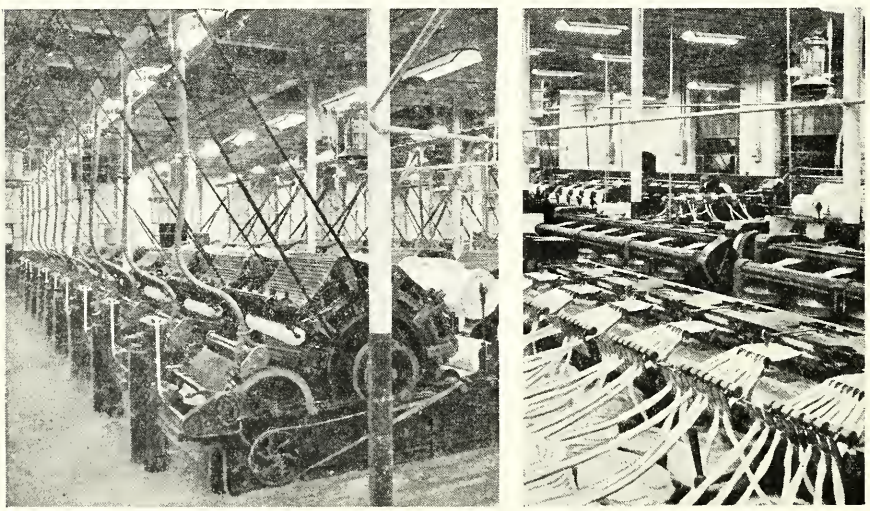


FIG. 10-81. Typical cotton-mill lighting installations for: a. carding operation; b. drawing operation.

Operations such as *slubbing*, *spinning*, *spooling*, and *warping* present more severe seeing tasks. The basic seeing task in all of these operations is to detect broken ends as soon as the break occurs and to make immediate repairs. Loss in production is a result of stopping an entire machine while repairs are being made on one thread. A minimum illumination level of 20 footcandles is recommended for these tasks. Although general lighting is needed to minimize contrasts, most of the light is concentrated on the working area. Most of the work areas of these machines are relatively long and narrow. A linear source aids in the elimination of shadows and has the desired light distribution characteristics.

Drawing in. This is probably the most difficult seeing task in the mill because of the small size of the details to be seen and the unrelenting visual concentration required. In this operation, the warp ends are drawn by hand through drop wires, harnesses, and reeds with a thin instrument called a reed hook. At any one time the operator's attention, as he moves from one side of the warp to the other, is confined to a space about 4 inches square. This task requires a minimum of 100 footcandles of well-diffused illumination such as would be provided by fluorescent luminaires of the two 40-watt lamp type hung over the operator's head and aimed at the work. Another satisfactory solution of this problem is to use a 60- or 100-watt incandescent lamp in an industrial reflector of parabolic shape, designed to be moved from one side of the frame to the other as the work progresses. Whichever system of local lighting is used, the surrounding areas should be uniformly illuminated to a level of at least 10 footcandles.

Automatic tying in. The ends of a full loom beam are tied to the ends of a loom beam which is nearly exhausted, whenever possible, in order to eliminate the drawing-in operation. The work lies primarily on a horizontal plane. Prolonged visual effort is involved, and localized general illumination of 50 to 100 footcandles should be provided. A diffusing luminaire similar to the industrial fluorescent type or a special local incandescent type should be supplied for each operator.

Weaving. Weaving involves visual tasks of various degrees of difficulty. The warp strands which run lengthwise of the cloth are drawn through the eyes of heddle wires which create the bobbin shed. Illumination has to be furnished for the "fixer" to repair and oil the loom, for the "cleaner" to brush away lint, for the "creeler" to fill its bobbin creel, for other operators to install the full loom beams with accessories, and for still others to remove the full cloth roller. Broken ends must be located and "pulled in" (repaired), defects in the cloth must be "picked out" (removed by picking out the yarn from the filling bobbin), and the cloth must be inspected as it is woven. The most difficult of these tasks in the manufacture of gray goods is to see the detail of the finished cloth well enough to determine whether or not all of the specifications for perfect material are being met. (See Fig. 10-82.) More difficult tasks are met when weaving dark materials.

The looms are designed to stop automatically when an end breaks; however, there are defects which are not the result of a broken end. It is

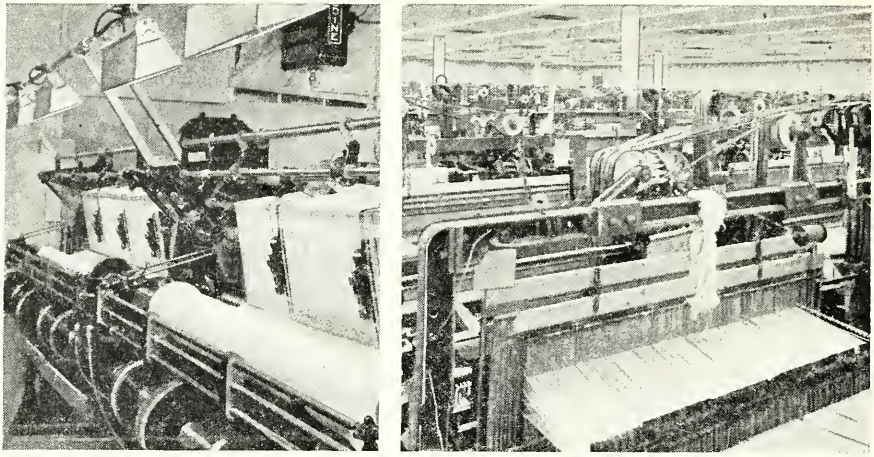


FIG. 10-82. Typical weave-shed lighting installations.

possible also for ends to break and cause a defect without the drop wires falling and stopping the loom. These more obvious flaws must be noted in addition to the smaller ones, such as a bent reed, too many ends through one opening between the reeds, lint on the back of the loom which will in time cause a break, etc.

Shadows are a real problem in a weave shed. Light sources in the back aisle cast machine shadows on the work; those centered on the loom over the work aisle may cast shadows of the weaver's head. The ideal location for the luminaire is directly over the loom. To soften shadows, the luminaire should be large in area. A standard dome-type reflector, mounted over each loom, has been found satisfactory. One luminaire mounted over the work alley between each pair of looms has some advantage in initial cost; however, the resultant illumination is less desirable because of the increased possibility of shadows.

Inspection. Inspection is a specialized task peculiar to each mill. A minimum illumination level of 50 footcandles is recommended and higher levels often are desirable.

Silk and Synthetic Fiber Plants

Soaking and fugitive tinting. Preparatory to twisting or throwing, yarns which are received in the form of skeins are soaked or lubricated. Also, they may be fugitive-tinted during the same operation. Tints are used to identify the direction and amount of twist and occasionally to distinguish different lots of yarn.

The soaking operation may be carried out in a number of different ways; the simplest is to submerge a number of skeins in a tank of soaking solution. It is not necessary to see the individual threads, and the visual effort required during the process is not great. Uniform illumination should be provided throughout the entire working area. The minimum level recommended is 10 footcandles. Either incandescent- or fluorescent-lamp luminaires are satisfactory.

Winding or spooling. Each skein is mounted on a light wooden or wire-wheel-shaped frame, known as a swift, from which the thread is wound onto a horizontal friction-driven spool. The machines, which may be of either single- or double-deck construction, normally are arranged in rows. Single-deck machines usually are used unless floor space is at a premium.

When the thread is broken during the winding operation, the ends must be found against a background consisting of the rest of the thread on the skein and the spool. Since the contrast is extremely low, the visual task is very severe and touch is relied upon to a very large extent.

Thirty footcandles is the minimum recommended illumination for the spool and the portion of the swift which normally is in the field of view. This level can be provided by locating the light source in the center line of the aisle between the machines. Either a trough reflector or industrial diffusers may be used. Both incandescent- and fluorescent-lamp luminaires have been found satisfactory.

Doubling and twisting. The seeing problem is similar to that in winding. Good illumination is needed throughout the entire length of the threads from their origins on the spools of untwisted thread to their terminations on the receiving bobbin. The machines ordinarily are arranged in rows, but are higher than winding machines. The lighting requirements, which are similar to those for winding, although in many cases considerably more severe, may be met with either a direct-lighting trough reflector or with closely spaced industrial diffusing units. A level of not less than 30 footcandles is recommended for white threads and 60 to 90 footcandles is recommended when work with colored thread is involved. Most twisted yarns are fugitive-tinted.

Conditioning or setting of twist. It is not necessary to see individual threads. The seeing problem is not difficult. General illumination of not less than 10 footcandles is recommended throughout the working area.

Rewinding. The visual requirements are similar to those of winding or twisting. An illumination of 30 footcandles or more for high-reflectance threads is recommended, and from 2 to 3 times this value for low-reflectance threads. The same type of installation as for winding is recommended.

Coning. The lighting problem is much the same as that involved with other types of throwing machinery, except for the existence of the aisle giving access to the rear of the machines. At least 30 footcandles is recommended for work with light threads, and from 50 to 100 footcandles for work with colored threads. A diffusing type of luminaire is recommended.

Quilling. Light should be supplied on the spool or cone from which the thread is being wound, on the quill on which it is being received, and on the entire length of the thread between them. The thread must be seen against a low-reflectance background, consisting of various parts of the machine. An illumination of not less than 30 footcandles is recommended for white threads. When dark or tinted threads are used the illumination should be from 50 to 75 footcandles.

Warping. The spools necessary to supply all the warp ends required for a single section are mounted on the creel and are threaded through the appropriate spacing devices (reeds) and tension-control apparatus. (See Fig. 10–83.) All the ends in one section are gathered together in a single knot and hooked to a pin on the reel. As the reel rotates, the yardage is indicated on a large dial. After a section has been completed, knotted, and tied, the next section is placed on the reel alongside the first by exactly the same process until the required number of warp ends has been obtained.

Through the action of drop wires at the top of the creel, the machine will stop automatically if an end breaks or the tension fails. If the break occurs at the creel, it usually is possible to locate both ends and splice them directly, but if it occurs at the reeds, the location of the end on the creel is somewhat more difficult.

Good illumination on the creel is necessary to enable the operator to locate and repair the broken ends and to place new cones, the threads of which must be tied to the ends of the threads on the cones in use.

The recommended illumination at the top of the creel is 50 footcandles or more, with the greatest practicable uniformity throughout.

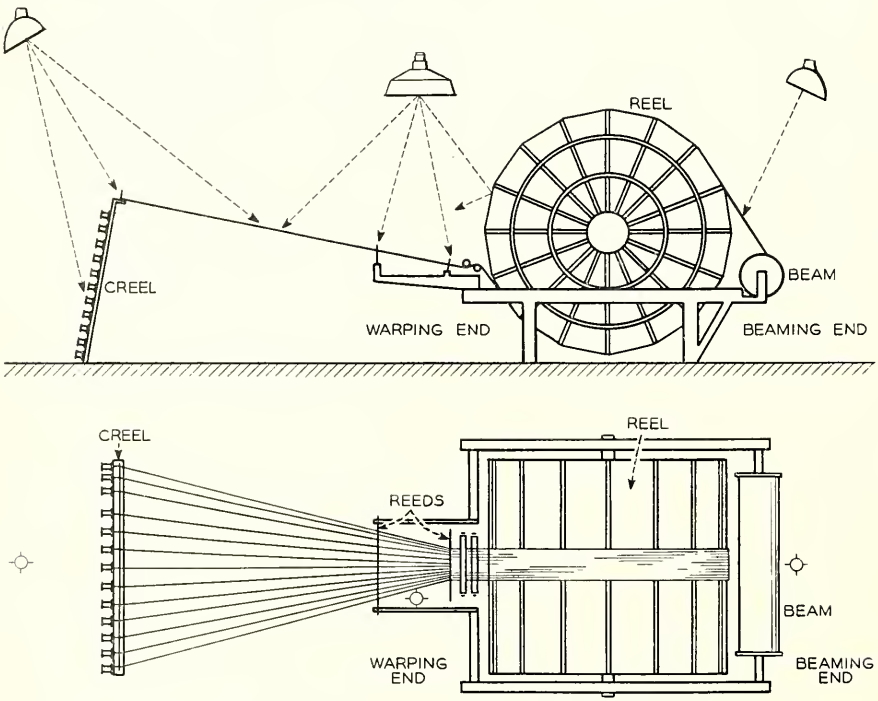


FIG. 10-83. Plan and elevation of inclined-creel silk warper.

Drawing in or entering. Throughout the entire process it is necessary to see the threads against a low-reflectance background comprising the mass of heddles. The seeing task is very severe for both operations. Accordingly, the illumination recommended in the plane of the heddles is 100 footcandles or more. General illumination supplemented by concentrating luminaires may be used. The concentrating luminaires should be fixed in position and should illuminate the entire working area without repeated adjustments by the worker.

Weaving. Weavers are constantly on the alert to see that looms are producing according to specifications. A loom may continue to operate after an end has been broken if the drop wire fails to fall. Other causes, such as a bent reed, produce defects which can be determined only by an inspection of the cloth. These defects should be located as soon as they occur so that corrections can be made and high shrinkage losses avoided.

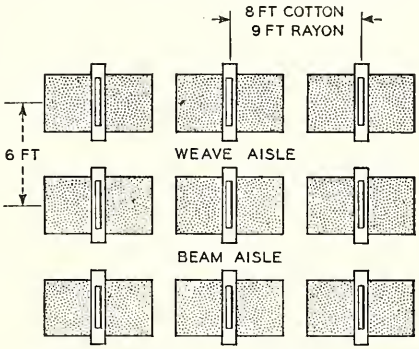


FIG. 10-84. Recommended lighting installations for silk, synthetic-fiber, and colored cotton looms. The spacing of the fluorescent reflectors down the loom row will be about eight feet on centers for cotton, nine feet for rayon. Luminaires should be mounted about 10 feet above floor, preferably below humidifiers.

Recommended illumination levels for silk and synthetic-fiber weaving are 30 footcandles for high-reflectance and 50 to 100 footcandles for low-reflectance threads. (See Fig. 10–84).

The fact that looms usually are arranged in long aisles and facing each other makes it possible to center the luminaires over the weave easily, thus illuminating the front of two looms with one luminaire. In wide-goods weaving, the shadow of the weaver on the loom usually is not objectionable as he ordinarily stands in such a position that his shadow is not on the portion of the work under observation.

For the back of the looms where the visual effort usually is less severe and not so prolonged, one luminaire (of the same lumen output) per four looms, with a higher mounting, will provide satisfactory illumination.

Burling and mending. The object of burling and mending is to locate and, when practicable, remove any defects in woven cloth prior to the final finishing process. Several types of defects may exist: (1) broken filaments and knots; (2) loose filling; (3) slack or tight ends; (4) pulled warp; (5) temple cut, and (6) stretched yarn.

Each of these six defects can be observed best in silhouette against a flashed-opal glass plate, lighted from beneath. The optimum brightness of the plate is a function of the transmittance of the sample, high for low-transmittance (opaque) materials, and low for high-transmittance (sheer) fabrics.

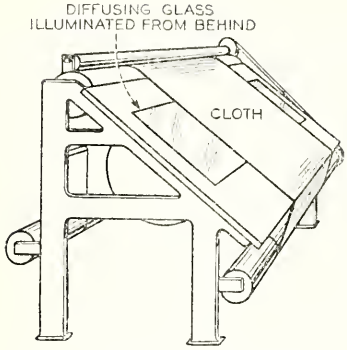


FIG. 10-85. A burling and mending table.

For the best silhouette vision the illumination on the cloth should be low. A brightness of one hundred to four hundred footlamberts for the flashed-opal glass plate has been found satisfactory for some purposes. The opal glass plate should be set at an angle of 45 degrees. Cloth is drawn over it at a fairly rapid rate. (See Fig. 10-85.)

Silk-hosiery knitting. This machine operation presents a severe seeing task. A line source installed directly above the front of the machine and illuminating an 18-inch strip the length of the machine to a minimum level of 30 footcandles in service is recommended. Luminaires should be at least $7\frac{1}{2}$ feet from the floor. Continuous fluorescent-lamp luminaires or a row of five or six 200-watt incandescent lamps in dome reflectors are recommended.

Woolen and Worsted mills

The seeing problems in woolen and worsted manufacture are, if anything, more severe than in cotton, and are more nearly comparable to conditions encountered in silk and synthetic-fiber manufacture.

Carding, *picking*, *washing*, *combing*, *twisting*, and *dyeing* are routine operations comparable to similar tasks in silk and synthetic-fiber plants. The minimum general illumination recommended is 10 footcandles for high-reflectance yarns. The level should be increased to compensate for low-reflectance yarns. Either fluorescent- or incandescent-lamp luminaires are recommended.

Drawing in and warping. These operations present severe seeing tasks. A minimum illumination level of 100 footcandles provided by local diffusing luminaires is recommended.

Weaving. Twenty footcandles is the minimum illumination level recommended for high-reflectance goods. When the yarn is dark, a 100-footcandle level is recommended. Plants processing both light and dark goods should provide the higher level. Since the reflectance of wool fibers is diffuse, whereas that of the rayon and silk fibers is specular, the location of the luminaires with respect to the operator is not as critical.

Knitting. A minimum general illumination level of 20 footcandles is recommended for knitting machines for such articles as stockings.

CLEANING AND PRESSING

The operations in dry-cleaning plants are functionally divided as follows:

1. Receiving.
2. Checking and sorting.
3. Dry cleaning.
 a. Naptha-solvent process.
 b. Synthetic-solvent process.
4. Steaming.
5. Examining and spotting.
6. Laundry or wet cleaning.
7. Repair and alteration.
8. Machine finishing.
9. Hand finishing.
10. Final inspection.
11. Shipping.

Receiving. Cleaning and pressing establishments receive soiled items from their pick-up trucks at a receiving platform at which garments are transferred from motor truck to hand truck. The garments are then wheeled to the checking and sorting tables. The recommended minimum illumination level for the receiving platform and passage is 10 footcandles.

Checking and sorting. For special instructions a checker reads a driver's ticket written in pencil attached to incoming garments and pins tags numbered in indelible ink to each garment for matching with the original ticket after the completed operation. Pockets are searched for matches or articles of value and finally the sorter divides the garments into silks and woolens, dark and light colored, or other classifications necessitated by the cleaning operation. The penciled notations are difficult to read. Contrast, as well as the handwriting, often is poor. The minimum recommended illumination level is 20 footcandles.

Dry cleaning by the naphtha-solvent process. The solvent used in this process is inflammable and under certain conditions explosive. For this reason the cleaning operation is carried on in a separate building or in a section of the plant divided off by a firewall. *Explosion-proof lighting equipment is mandatory.*

No attempt is made in the washing and drying room to determine whether the cleaning has removed all spots and no other difficult seeing problems are involved. A minimum average illumination level of 10 footcandles is recommended. The explosion-proof fixtures must be located so the washer, extractor, and drying-tumbler interiors are well illuminated when the covers are thrown back. (See Fig. 10–86.) In addition, distribution must be such as to light properly pressure and flow gauges on the filters and in the piping. The time of washing is largely determined by the

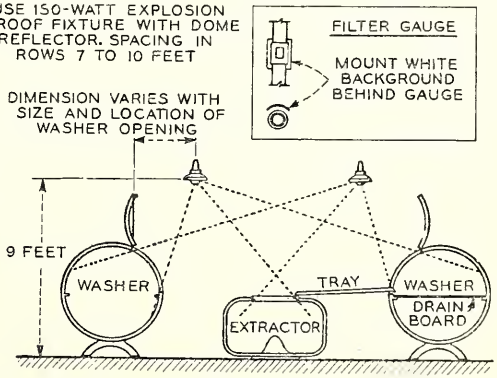


FIG. 10-86. Elevation of lighting installation for the naphtha-solvent process of dry cleaning.

clarity of the naphtha coming from the washer. This dirt can best be seen in silhouette against a white background while it is passing through the filter gauge.

Dry cleaning by the synthetic solvent process. This process differs from the naphtha type in using a nonexplosive solvent and a closed system. The seeing tasks are related to loading and unloading the cylinder and reading the various temperature, pressure, and flow gauges. Light should be directed into the cylinder and toward the gauges from locations such that an image of the source will not be formed in the field of view.

Examining and spotting. The dry-cleaning process takes practically all of the oil and grease out of stains of various types unless it is ground into the fabric very firmly. Nearly always, however, some spots remain to be taken out by water spotting. Many stains have characteristic colors by which they may be identified by a skilled "spotter."

Through long experience this workman is trained to detect, classify as to type, and remove all types of spots after choosing the proper chemicals. The critical seeing task lies in detecting the spot and its type. An explanation for the usual large number of the garments rejected during final inspection, for most of those sent back by customers, and for many garments stained by chemicals during spotting, can be found in the inability of the spotter to see the stains and identify them.

After the washing process, spots present a very subdued appearance with little contrast between themselves and the material. Also, the reflectance of many materials has a strong specular component. It is current practice for spotters to work under a screened skylight or along north-wall windows. Here when the weather is favorable the illumination level varies between 50 and 200 footcandles and the light is well diffused. Except on dark days and in direct sunlight, the natural illumination is considered satisfactory by most cleaners. Electrical illumination used to extend the working hours should blend well in color with daylight. (See Section 4.)

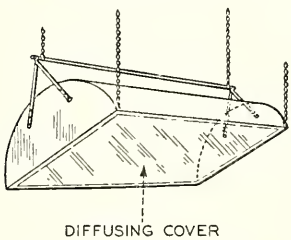


FIG. 10-87. Large-area, low-brightness luminaires are recommended for use over spotting tables in dry-cleaning plants.

A level of 150 footcandles or more provided by a low-brightness, large-area source is recommended. (See Fig. 10–87.) The face is covered with tracing cloth as a diffusing medium. A similar luminaire containing six 100-watt daylight fluorescent lamps gives off less heat and can be made to have a more shallow cross section.

Repair and alteration. Both hand and machine sewing is done in this section, often with dark thread on dark material. For hand work a general illumination level of 50 footcandles of well-diffused light is recommended. Supplementary illumination at the needle point of the machines sufficient to raise the level to 200 footcandles is recommended.

Machine finishing. Machine presses usually are lined up in a row for convenience and for minimum cost in the steam-piping installation. The

operator combines speed with good workmanship. Each garment is moved several times as a small section is finished and another moved onto the buck (working surface). The workman watches to see that all wrinkles are eliminated. The buck of the press should be uniformly illuminated without shadows from the head of the press or the workman's body. Crosslighting from two sources is recommended. (See Fig. 10–88.) This method takes care of the working area on the buck and in addition illuminates the clothes racks, aisles, and machine space. A minimum level of 30 footcandles is recommended.

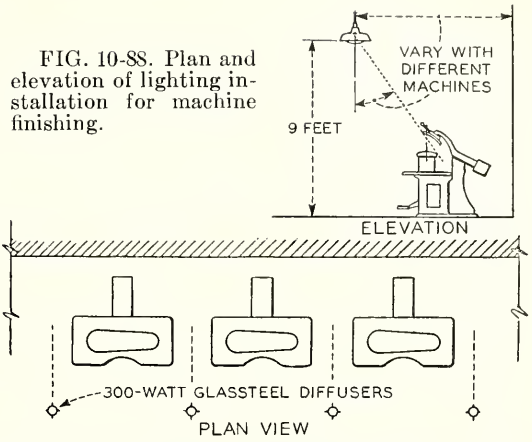


FIG. 10-88. Plan and elevation of lighting installation for machine finishing.

One of the most difficult tasks is to prevent double creases in trouser legs. A concentrating reflector at the rear of the buck causes a crease to cast a shadow, making it more easily discernible.

Hand finishing. Hand finishing (ironing) boards usually are installed in rows spaced $3\frac{1}{2}$ to 5 feet apart. The volume of handwork is decreasing gradually because of improvements in machines. However, the hand iron still is used to achieve the best results on lightweight materials. The hand finisher watches to see that wrinkles are eliminated, that the garment is completely pressed, that it is not scorched, and corrects minor defects.

The seeing task is moderately critical because careful handling of the iron is required for pleats, shirring, ruffles, and trimming. A 50-footcandle level should be provided.

Final inspection. Garments on individual hangers are delivered to the final inspector on portable racks or by a power-chain conveyor. Each garment in turn is removed from the rack and hung on an overhead support in such a way that it will rotate easily. The inspector examines the garment carefully, watching for inferior finishing, for spots, for damage done to the material during the cleaning process, and for completion of any customer-ordered repairs or alterations.

The owner relies on the inspector to make sure that the garments leaving the plant are properly cleaned and finished. Most of the critical visual work is done with the garment at approximately a 45-degree angle with the vertical and at short range. The lighting requirements are about the same as for spotting. A 200-footcandle level of well-diffused illumination from a large luminaire mounted directly in front of the garment support and at least 8 feet above the floor is recommended. To increase the vertical plane illumination the luminaire should be tilted parallel to the usual garment plane.

Shipping. The shipping section covers the garments with protective paper bags, attaches the original ticket, and loads the delivery trucks. The identifying tags attached to the garments often are difficult to read because the ink is partially washed out during the cleaning process. A minimum illumination of 30 footcandles is recommended for the wrapping area and the shipping table. Ten footcandles is recommended for other parts of the shipping section.

Laundry or wet cleaning. On some garments the spots are so numerous, large, and widely distributed that it is uneconomical to use the spotting method for removing them. Each cleaning plant maintains a small laundry for such garments. A conventional cylindrical washer, centrifugal extractor, and drying tumbler are used. The lighting problem is very similar to that of the dry-cleaning operation. Vapor-proof luminaires with diffusing opal glass covers and enamel reflectors are recommended. Luminaires must be located so as to light the interior of the machines and provide a level of at least 10 footcandles.

CANDY MANUFACTURING

In compliance with stringently enforced pure food laws and to foster good will, progressive candy manufacturers utilize every means for promoting cleanliness and efficient plant operation. New plants are constructed to utilize the greatest possible amount of daylight, but some still have inadequate and inefficient electric-lighting systems.

Chocolate Making

In the manufacture of chocolate, the cacao beans first are toasted and then are passed through shell-removing machines. The bean then is conveyed by gravity feed to the crushers which press out liquid cacao butter. After milling and mixing with powdered milk and confectionery sugar, the pulverized beans are pressed through a series of rollers and then mixed with the cacao butter in a conche.

Many of these operations are gravity fed and utilize portions of two or three floors in a large plant with conveyors or chutes passing through the floors. There is very little handwork because practically all processes described are

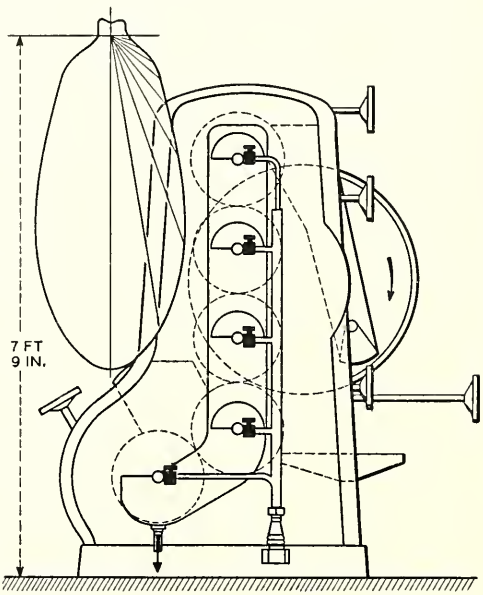


FIG. 10-89. Typical five-roller refiner. Periodic adjustments are made at the five rollers. Light should be distributed so as to illuminate the entire refining area.

confined to the inside of hoppers, refiners, conches, and other machines. Consequently, no difficult seeing tasks are encountered in chocolate manufacture.

A level of illumination of not less than 10 footcandles is recommended for the chocolate-processing sections of the plant. However, 25 footcandles is recommended for the five rollers of the roller mill, where a careful setting of the rollers must be made periodically. Supplementary lighting, having a predominant vertical component, should be used at this point. (See Fig. 10-89.)

Chocolate Dipping

Dipping is carried on in various sections of large plants, because this arrangement facilitates the manufacture and minimizes the conveyance of the different fillings. Dipping tables generally are located symmetrically in the area provided, with the operator sitting beside a depressed section of the table. Drippings from the operator's fingers are set in a design on top of the candy for decoration. The dipper must see the relative position of the drippings from the hand over the confection in order to make a neat and orderly design. A diffuse, uniformly distributed illumination level of not less than 20 footcandles on the work should be provided in each dipping room.

Cream Making

Glucose, which is the base for most creams and fillings, is cooked, beaten by paddles, then remelted and recooked to increase its viscosity. It is then flavored, beaten again, and finally pressure-formed in plaster-of-Paris molds. The seeing task in cream making is of moderate severity. A general illumination level of the order of 20 footcandles provided by diffusing luminaires is recommended.

Kiss Wrapping

A kiss-wrapping production line consists of many individual kiss-wrapping machines, arranged on both sides of a belt conveyor. General illumination of not less than 10 footcandles should be provided over the entire area, with supplementary lighting of 50 footcandles at the critical seeing points. These vary in location with the type of wrapping machine.

Gum Drop and Jellied Form Making

In this process plaster-of-Paris patterns are used to make smooth molds of fine-milled cornstarch. The molds are arranged symmetrically in shallow wooden trays which then are moved into such a position by a belt conveyor that one row of molds is placed directly under a series of injectors which automatically place the proper quantity of syrup in each. This operation is repeated until all molds in the tray are filled. In mold-fillers for gum drops and similar candies, the automatic injectors which press the fluid candy into the molds are kept clean by an attendant.

A minimum uniform illumination level of 20 footcandles provided by a concentrated source hung above the equipment and directed toward the molds is recommended.

Hard Candy Making

In the manufacture of hard candy, sugar is cooked, flavored, and placed on water-cooled tables in a semisolid state where a batch is kneaded into an oblong shape. Fillings are added at this stage. The batch then is worked into a cylinder about 10 inches in diameter and 6 feet long. After tapering in a heated canvas hammock the point is fed through a die-casting machine (Fig. 10–90), which automatically shapes and cuts the candy.

Twenty footcandles of general illumination should be provided for ingredient mixing and cooking, and the levels should be increased by supplementary lighting to a minimum of 50 footcandles at the die-casting machine. Supplementary luminaires should be located between the operator and the die-cutting machine. Because of the specular reflectance of hard candy, luminaires with a large low-brightness luminous surface should be centered 4 feet above each hand-mixing table. Continuous fluorescent-lamp luminaires also may be used. An illumination level of not less than 40 footcandles is recommended.

Assorted Candy Packing

There are three methods of packing candy:

1. *Progressive method.* In the progressive method candy is placed in simple containers in front of the operators who sit on each side of a long table along the center of which extends a belt conveyor.

2. *Stationary method.* In the stationary method long flat tables, 36 inches high and 36 inches wide, are used. Directly over the center of the table a stock rack, 18 inches wide, is suspended from the ceiling or fastened to the table so that its bottom is 18 inches above the top of the table. The operator removes eight or ten different types of candy from the rack and packs them in a box in front of her.

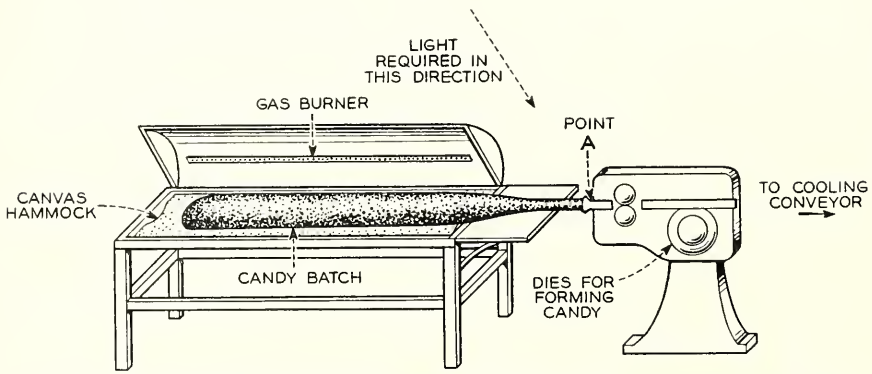


FIG. 10-90. Hard-candy-forming machine. The batch is revolved slowly in the canvas hammock. Heat is applied for surface glazing. The operator tapers one end to enter the dicing machine at point *A*, which cuts and forms in one operation and delivers the pieces to a cooling conveyor. An illumination level of 30 footcandles should be supplied at point *A*.

3. *Circular method.* In the circular method, which is not used as much as the other two, a ring table, 36 inches high and 18 inches wide, is used. The outside diameter is about 6 feet, the inside diameter about 3 feet. The operator sits on a swivel stool in the center. The candy to be packed is placed on the circular table, one kind to a container. By rotating her stool 360 degrees an operator is able to pick a complete assortment.

On the basis of visibility meter tests of all three methods, a minimum uniform illumination level of not less than 20 footcandles is recommended for the entire packing area.

Special Holiday Mold Candy Making

Holiday candy usually is made on the north side of the building where the best natural illumination is available to aid in the hand artistry generally required. At window tables operators with small artist's brushes decorate molded candy with a thin, colored mixture of cream filling. Because of the intricate positions in which decorations must be placed on the confection, and the fine details of the decorations themselves, the seeing task is severe. On the basis of visibility meter tests a minimum illumination level of not less than 50 footcandles is recommended. The color should blend with the daylight.

Box Making and Scoring

In many candy factories, containers and boxes are made on the premises in a department divided into two main sections, one devoted to making standard boxes, the other to special boxes.

Scoring, the first operation in making boxes, is mechanical. Care must be taken that the frame which holds the knives in position does not cast a shadow on the flat cardboard surface. All light sources should be located between the operator and the frame of the scorer, thus avoiding shadows under the frame holding the scorers.

Flat cardboard usually is fed over rollers at the front of the machine and the first set of scorings is made by circular knives. In manufacturing these boxes, scorings must be made also at right angles to the original scorings. A general illumination level of 20 footcandles is recommended.

After the cardboard has been scored, it is conveyed to a box-forming machine. This machine bends the cardboard at the scorings, applies the gummed corner supports, and automatically shapes the container. The machine is pedal-controlled, and all work is accomplished on a horizontal plane, with the tool and forming-die completing the work.

Most container stocks have a high reflectance compared with the machine background. The contrast usually exceeds 75 per cent. It is recommended that a minimum general illumination level of 20 footcandles be provided.

In decorating, much silver- and gold-colored foil is used. Most decorating operations include handwork facilitated by pedal-controlled presses.

Because of the specular reflectance of the coverings, it is recommended that large-area, low-brightness sources be used.

At the tables where art work on the containers is completed, 20 footcandles is the minimum recommended illumination level.

PRINTING AND COLOR ENGRAVING

Type Composition and Handling

Metal type handling and color control in modern color-reproduction processes present the critical seeing problems which are characteristic of the printing industry. A printer frequently works with a slug, galley, or form of clean type, or with a clean engraving or electrotype plate. Each is a mottled metallic mirror. The raised type face usually has been inked at least once during the pulling of proof and therefore is darker than the bright specular surface of the clean shoulder. The shoulder or flat depressed portions act as a mirror against which the characters are silhouetted for inspection. Large-area luminaires are recommended for the areas of the plant in which type must be assembled or proved.

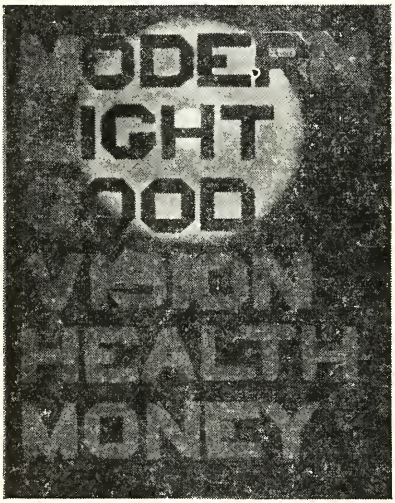
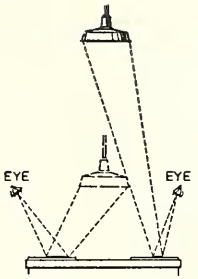


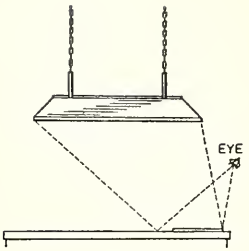
FIG. 10-91. Dark letters mounted on a silvered mirror (representative of fresh type slugs that have been proofed). The figure shows that characters are easily visible only when they lie within the image of a light source.

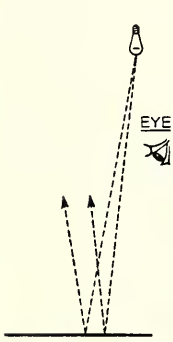
Figure 10-91 shows a mirror-like surface of type metal with letters pasted on it and lighted by a standard industrial reflector such as is found over the type cases and imposing stones in printing establishments. Note that of all the characters only those few that are within the reflector image are revealed. In installations with luminaires mounted 8 or more feet above the floor, the size of the image of this type of luminaire, when viewed by a compositor, usually is less than 4 inches in diameter. Many printers have discovered that if they drop the reflector to the lowest feasible position, they can see the type better. When the reflector is lowered, the size of its image is increased and therefore silhouettes more of the characters (Fig. 10–92.)

In an ordinary type character, the edges where the bevel joins the shoulder and at the face are rounded by use into tens of thousands of concave and convex mirrors. (See Fig. 10–93.)

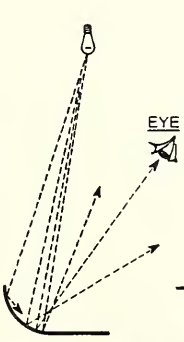
Fig. 10-92. Graphical illustration of the value of lowering the ordinary factory reflector over the imposing stone. The ideal condition is represented by the right-hand figure.



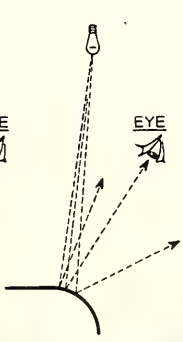




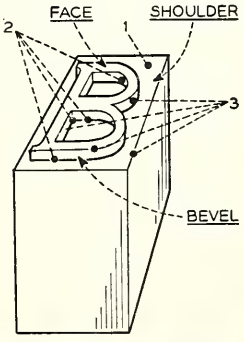
1-PLANE MIRROR



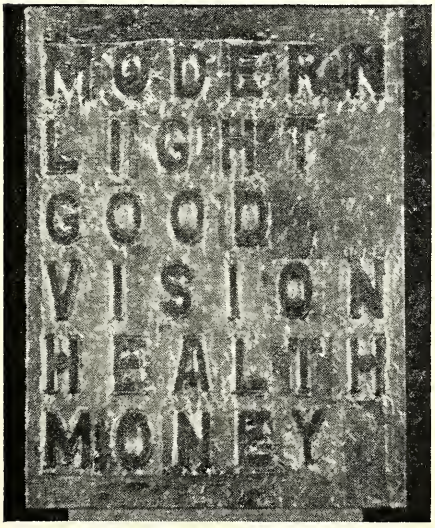
2-CONCAVE MIRROR



3-CONVEX MIRROR



TYPE



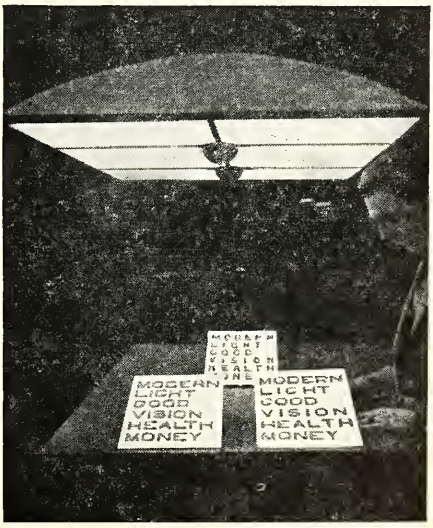


FIG. 10-93. Reflections from type: (above) If the light source is small in area reflections will be glaring. (at left) In an ordinary form there are many thousands of tiny filets and rounded corners that act as concave and convex mirrors to reflect light into the eye. (at right) When a large low-brightness source is used characters become more legible because glare is minimized.



FIG. 10-94. Luminaire for compositors in printing establishment.

If the image of the luminaire is to cover the entire galley or form its area should be at least as large as the form and preferably should be as large as the stone. A luminous ceiling is ideal. The large luminaire shown in Fig. 10–93 has a 36-inch by 56-inch rectangular luminous area. It will be noted that every character on the several mirrors is silhouetted plainly against the image of the luminaire. Fluorescent-lamp luminaires with diffusing covers are particularly well adapted to this application. (See Fig. 10–94.)

Illumination for compositors' cases and imposing stones should possess the following characteristics:

1. The luminaire used should have a low uniform brightness. This excludes any fixture with bare or frosted incandescent lamps that are partially exposed in the direction of the type.
2. The luminous area of the fixture must be large.
3. The image of the luminaire visible to the worker should cover the entire form.
4. The illumination level at the type should be not less than 50 footcandles.

Machine Composition

Linotype, Intertype, and Monotype machines usually are equipped with local lighting equipment by the manufacturers. Fluorescent-lamp luminaires should include two lamps operated out of phase to minimize stroboscopic effect. Large-area, low-brightness luminaires should be used to provide the minimum recommended illumination level of 30 footcandles.

Press Room

On the bed of a typical two-revolution flat-bed cylinder press, it is necessary to discriminate fine detail during make-ready and register operations. A minimum general illumination of 30 footcandles is recommended.

Pressmen need a large-area, low-brightness light source, such as recommended for the composing table and type case, but low head room under the feed board interferes with a simple overhead installation. Fluorescent-lamp luminaires also are well adapted to this application.

Color Reproduction

All persons who are responsible for quality control in color reproduction should use illumination of the same spectral characteristics. A screened table illuminated to a level of 50 footcandles of constant known spectral distribution is recommended for color inspection. It may be used with uniform, equally satisfactory results by day and night shifts. It should be conveniently located with respect to a group of presses. The screening surfaces should have a nonselective reflectance, that is, they must be either neutral white, gray, or black. A color-inspection table may be combined with a mark-out booth. (See Fig. 10–95.)

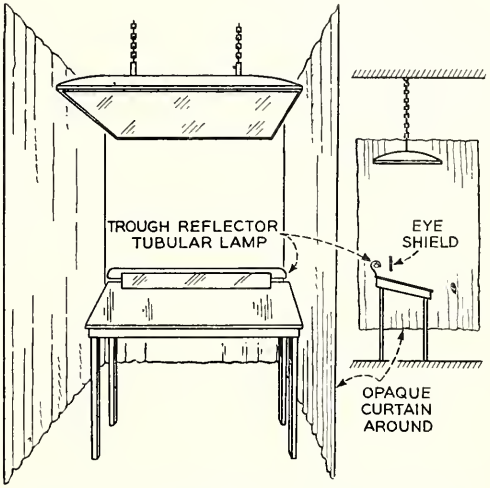


FIG. 10-95. Combination inspection and mark-out booth. Note eye-shield or baffle for elimination of glare when observing type impression.

PETROLEUM AND PETROLEUM PRODUCTS

In oil and petroleum products manufacturing plants, various types of lighting equipment are utilized to provide illumination to facilitate different visual tasks. When planning an installation, a maintenance factor not greater than 0.65 should be used unless detailed maintenance data are available. Numerical values of illumination recommended in the following paragraphs are maintained values based on this factor.

Process Equipment Buildings

In oil- and water-pump houses, compressor and filter buildings, etc., uniformly distributed illumination levels of 8 to 10 footcandles are recommended. Because of piping and equipment located near the ceiling in such areas, a symmetrical layout and uniform mounting height of luminaires must in some cases be modified in order to prevent shadows.

Two general types of luminaires may be used. Where locations are described as Class 1, Group D *hazardous*, explosion-proof luminaires equipped with strong reflectors such as shown in Fig. 10–71, or with other suitable types, should be used. At nonhazardous locations (pump rooms for processing heavy oils, etc.) in which a corrosive but nonexplosive atmosphere prevails, vapor-tight luminaires such as shown in Fig. 10–96 may be employed. Luminaires within reach, or otherwise exposed to breakage, should be equipped with metal guards.

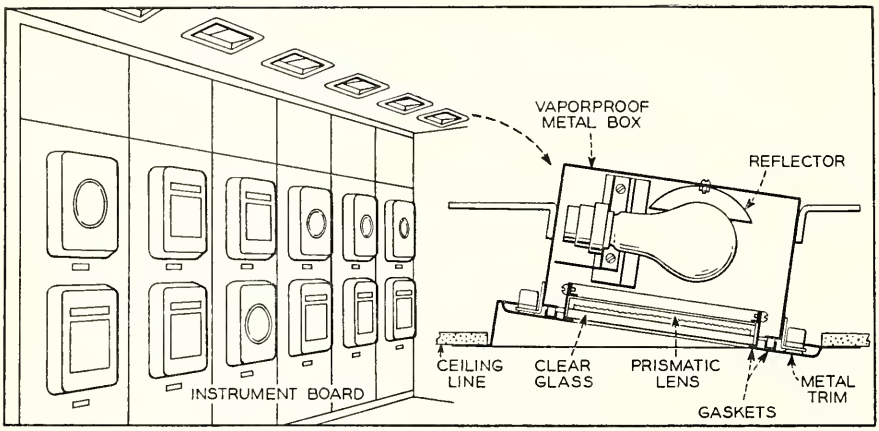


FIG. 10-96. Incandescent-lamp luminaire installation for an instrument board. The luminaire consists of a vaporproof metal box containing two 100-watt incandescent lamps and a prismatic lens. The lens aims a fan-shaped beam at a line located approximately one-third of the distance from bottom to top of the instrument board.

Instrument Boards & Individual Instruments

Instrument boards which contain indicating and recording pyrometers, flow controllers, gauges, level indicators, etc., are located in most cases in separate control rooms. A vertical illumination level of 30 footcandles on the instrument portion of the board is recommended. Luminaires should be located directly in front of and above the instrument boards, and in such a manner as to minimize specular reflections from the instrument windows in the observer's field of view. Either incandescent or fluorescent luminaires may be used. Where hazardous explosive conditions may exist the air pressure within luminaires should be maintained higher than that in the room by means of pipe connections to a blower or compressed-air system which draws air from a gas-free location. An allowance of approximately 80 to 100 watts per foot width of an instrument panel may be required for the lighting of the panel. To meet rigid "explosion-proof" requirements, luminaires such as shown in Fig. 10–71 may be used.

Individual instruments and gauges. Luminaires with angle-type reflectors are recommended for lighting individual instruments. Liquid column gauges often have built-in luminaires or can be illuminated by special "gauge-light fixtures" mounted either in front or in back of the gauge glass.

Special Equipment

Special lighting equipment often is required, such as that for illuminating the insides of filters or other equipment whose operation must be inspected through observation ports. If the equipment does not include built-in luminaires, concentrating-type reflector luminaires should be mounted at ports in the equipment housing.

Portable luminaires are utilized where manholes are provided for inside cleaning and maintenance of tanks and towers. Explosion-proof types (where hazardous conditions may exist) with 50-foot portable cables are connected at industrial receptacles (either explosion-proof or standard) provided near manholes on towers and at other locations.

Outdoor Tower Platforms, Stairways, Ladders, Etc.

An illumination level of 2 to 4 footcandles is recommended for unobstructed platforms, upper and lower landings of stairways, and ladders. Luminaires should provide uniform illumination and should be shielded from the direct view of persons using these facilities. On unobstructed platforms 150–watt incandescent lamps spaced on 12- to 18-foot centers usually are adequate. Special luminaires often are required at gauges. Vapor-proof and weather-proof luminaires equipped with refractors or clear vapor-proof covers may be used. Luminaires above top platforms or ladder tops should be equipped with refractors or reflectors. Reflectors may well be omitted on intermediate platforms around towers so that the sides of the towers will receive some illumination and the reflected light therefrom will mitigate sharp shadows.

Oil heaters (furnaces). Oil heaters are tower-like and require illumination at their firing fronts, at their sides, and on platforms, stairs, and ladders attached to the heater structure. This may be provided by an installation of vapor-proof, incandescent-lamp luminaires (150- or 100-watt) attached to the structural frame, or by means of 300- or 500-watt, incandescent-lamp floodlight or asymmetric refractor units mounted on poles around the heater, or on adjoining structures where such are available. Electrical convenience outlet receptacles for portable luminaires are necessary for maintenance purposes.

Outdoor areas around buildings and structures. Where buildings and structures are close together, local vapor-proof or explosion-proof luminaires mounted on brackets at doors or hung from structures, pipe supports, etc., are satisfactory.

For large areas, illumination should be provided by means of refractor-type luminaires mounted on steel or wood poles, 25 to 35 feet above grade. Vapor-tight floodlights utilizing 300- to 1,000-watt incandescent lamps also can be used where high structures are available for mounting them.

SHOE MANUFACTURING

Shoe-manufacturing processes may be separated into three groups according to the type of seeing tasks involved in each:

1. Simple seeing tasks include:

Leather: storage, staying, sole laying, beveling, nailing, heel scouring, burnishing, spraying, box making, dinking, last racks, lasting, pulling over, trimming, channeling, heel breasting, edge setting.

Rubber: washing, compounding, calendering.

2. Seeing tasks of average difficulty include the mechanized operations:

Leather: skiving and splitting, treeing, welting, rough rounding, perforating, buttonholing, eyeletting on both light and dark materials, certain types of bench work.

Rubber: sole rolling, milling, completed stages of compounding.

3. Seeing tasks of considerable difficulty include:

Leather: cutting, bench work, stitching, inspection, rounding, sole stitching, fine edge trimming on both light and dark materials.

Rubber: cutting, making, calendering.

Recommended levels of illumination for typical manufacturing operations are given in Table 10-15.

Leather-Shoe Manufacturing

Sole department. In a sole department, leather, sorted for grain and thickness, is stored in 5- to 6-foot piles on low platforms which are arranged with passageways between them. A uniform illumination level of about 10 footcandles throughout the storage area is recommended.

For grading according to color, some advantage may be gained by the use of illumination of spectral characteristics similar to daylight.

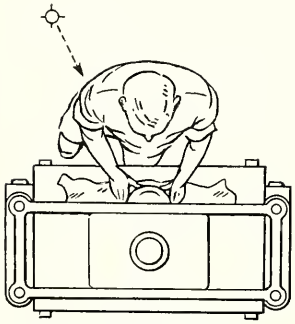


FIG. 10-97. Leather shoe manufacturing: The operator of a beam dinker holds a die and regulates pressure on the die with his foot. Light should be projected to the machine from the right and to the back of the operator to eliminate objectionable shadows

Beam dinkers. A beam dinker stamps soles and insoles out of hides by means of dies. (See Fig. 10-97.) It consists of a heavy cast-iron frame and a large beam that exerts pressure through a vertical motion on a cutting die. There is some hazard of finger injury in operating the machine. This may be minimized by a localized general lighting installation which provides an illumination level of 20 footcandles on the die.

To avoid casting shadows of the beam on the platform, all luminaires in the area occupied by the beam dinkers should be placed at the operator's side of the machine.

Last storage. Last storage bins usually are located in a segregated section of the sole department. Generally there is a 3-foot aisle between the bins. Luminaires with asymmetric distribution should be mounted

over the aisles so as to illuminate the bins in order that lasts may be selected.

To improve the lighting in the rear of the bin, wedges of aluminum may be laid across and fastened to the base of each bin at the front. The sides

Table 10-15. Recommended Levels of Illumination for Shoe Manufacturing

DEPARTMENT		FOOT-CANDLES
LEATHER SHOES		
Storage and Sole Leather Department		
Leather storage		10
Vamp storage		10
Last storage		10
Beam dinkers		20
Miscellaneous areas and aisles		5
Cutting and Stitching		
Cutting tables		20
Marking, buttonholing, skiving, sorting, vamping, counting	Light material	20
	Dark material	100
Stitching	General illumination	10
	Light material	30
	Dark material	100
Office and stock room		30
Making Department		
Stitchers, rough rounders, nailers, sole layers, shank nailers, welt beaters, trimmers, welt scarfers, welters, tack pullers, lasters, pull-overs, edge setters, edge trimmers, breasters, sluggers, levelers, randers, wheelers, channel layers	Light material	20
	Dark material	100
Sorting and storage areas		10
Aisles		5
Finishing Department		
Treers	Light material	20
	Dark material	100
Embossing, spraying, cleaning, scourers, buffers, polishers, hand repairers	Light material	20
	Dark material	100
Benches		20
Packing and Shipping Department		
Box making, bench work, shipping room		10
Office		30
Aisles		5
RUBBER SHOES		
Coaters and mill run compounding		10
Varnishing, vulcanizing, calenders, coating, upper and sole cutting		30
Sole rolling, lining, cutting, and all making operations		50
Office		30
Aisles		5

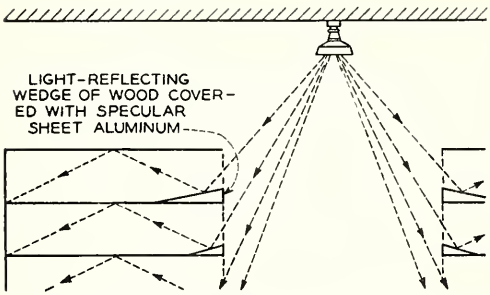


FIG. 10-98. Suggested use of light-reflecting wedges for last storage bins.

Note: It is recommended that walls and ceilings of all bins be painted with high reflectance paint.

and roof of each bin may be painted with a high-reflectance paint such as aluminum. Light striking these wedges, at the front of the bin, is reflected to the walls and ceiling, thus increasing the level of illumination by about 50 per cent in the bin interior. (See Fig. 10-98.) The polishing effect of the sliding leather over the wedges maintains the specular reflectance of the surface.

Upper department. An upper department generally is divided into the following sections: (1) sorting; (2) trimming, cutting, and staying; (3) lining; (4) upper cutting; (5) marking and skiving; and (6) assembling.

When an order is received for a certain grade of shoes, the sorting department grades the leather as to color and quality. For this work a uniform illumination level of 20 footcandles for light materials and of 100 footcandles for dark materials is recommended. The sorting department generally is located at the north side of the building so that skylight may be utilized.

Skilled workers then split each piece of leather into as many sheets as possible and cut out individual parts for uppers. This work generally is done on tables 30 to 36 inches above the floor.

The various pieces go to the counting department where they are counted and marked with job numbers. Skiving, which consists of the mechanical thinning of edges of the uppers so that they can be turned over to present a finished appearance, is the next step. The work of assembling consists of bringing together the various parts which make up the uppers such as lining, stay, vamp, counter, toe, tip, etc. For these operations a uniform illumination level of 20 footcandles for light materials and of 100 footcandles for dark materials is recommended.

Stitching department. In the stitching department the following operations are typical: (1) lining; (2) tip; (3) closing and staying; (4) boxing; (5) top stitching; (6) buttonholing and stamping; and (7) toe closing.

These operations present difficult seeing tasks. A uniform general illumination level of 10 footcandles should be supplemented by local lighting on the machines. It is recommended that this lighting be secured by fastening to the table, at each machine, near the needle point and on the right-hand side of the operator, an adjustable arm carrying an opaque reflector and a lamp. For light materials 30 footcandles on the work is recommended. For dark goods a level of not less than 100 footcandles of illumination is recommended. A ratio of supplementary to general levels of illumination as great as 10 to 1 usually is permissible.

Reflected light from the polished working surface of the machine should be cast over the right shoulder of the operator, between him and the operator on his right. This position also provides a secondary shadow across the leather just ahead of the needle point which improves visibility at the point of work because of the increased contrast.

For specialized work in this department such as eyeletting, buttonholing, perforating, etc., machines are used which have relatively large overhangs. These cause bad shadows when illumination is provided by luminaires mounted overhead. It is recommended that a local lighting system be used to supplement the uniform general illumination.

In all cases levels of illumination of not less than 20 footcandles should be provided on the work.

Making department. The making department in the average plant is subdivided according to operations as follows: (1) vamping; (2) welt-bottoming; (3) bottoming; (4) heeling; (5) turning; and (6) standard, screw, nail, or pegged shoe making.

In some plants this department is called the *gang room* and occupies an entire floor.

Usually this department is located in the factory area with the highest natural illumination level. A general electrical-lighting system also should be installed to provide 20 footcandles. Local lighting should be used to supplement the natural and electric lighting not only to provide at all times the high levels of illumination required at the work, but also to mitigate shadows of overhanging machine parts.

Lasters, sole layers, levelers, and nailing machines may be illuminated by diffused light. The source location is not critical. Other machines in the making department should be illuminated from the rear and to the right of the operator. The vertical as well as horizontal illumination level is most important. For recommended levels see Table 10-15.

Finishing room. In the finishing room shoes are inspected and faults are corrected. Treeing machines are used in this area for ironing out wrinkles. From here the shoe goes to the final inspection and thence to the packers and shippers. A uniform illumination level of 20 footcandles is recommended for this work if the materials have a high reflectance, and 100 footcandles if they have a low reflectance.

Packing and shipping department. The work in this department comprises matching and numbering shoes, inserting laces, and packing pairs in individual boxes on benches. In most plants shelves extend to the ceiling. The recommended illumination level is 10 footcandles.

Rubber-Shoe Manufacturing

In rubber-shoe manufacturing plants typical operations include the following: (1) washing; (2) compounding and milling; (3) cutting and calendering; (4) drying; (5) sole rolling and cutting; (6) making; (7) varnishing and vulcanizing; and (8) packing and shipping.

In the washing department crude rubber is cut up by band saws. A uniform general illumination level of 10 footcandles is recommended for

washing and cutting and also for the compound and mill area except where hoods are placed over the compounding machines. In such cases local lighting should be provided by luminaires installed under the hood with a reflector directed at the point of work.

As materials pass over the cutting and calendering machines, care must be taken to see that the coating is applied correctly. Calenders, especially the three- or four-roller type, should be lighted by luminaires on both sides of the machines. The light should be well diffused to avoid sharp shadows and glare.

After cutting or gumming, rolls go to the drying room where they are dried by steam heat. Where this department is confined to the center of the building and has no direct general ventilation, there is an explosion hazard. Where such is the case, explosion-proof or vapor-proof lighting units are recommended. Supplementary lighting equipment provides light at both front and rear ends of the sole rolling machine. An illumination level of 30 footcandles is recommended.

In the sole and upper cutting department, operators work rapidly with sharp knives. A uniform illumination level of at least 30 footcandles throughout the area is recommended. Luminaires should be mounted as high as possible. In some plants beam dinkers are used. These should be lighted in the manner described on page 10-130.

The making department is the most important in this type of plant. All parts are supplied, cut to shape, to bench workers who use cement to attach and complete a shoe. In some cases there is a shelf or rack over the center of the bench, extending its entire length. The lasts are placed on this shelf and if luminaires are placed over this shelf and hung low, the shelf causes a sharp shadow on the working areas of the bench. A general lighting installation producing not less than 50 footcandles on the work is recommended.

In the varnishing and vulcanizing areas, a uniform illumination level of about 30 footcandles is recommended.

FLUID MILK INDUSTRY

Recommended minimum footcandle values to be used for guidance in the solution of lighting problems in the fluid milk industry are included in Table 10-16.

Loading and Unloading Platforms

Areas used during dark winter mornings and evenings and at night for loading and unloading should be electrically lighted to a uniform minimum level of 10 footcandles. This should be supplemented by local lighting equipment to increase the level to a minimum of 20 footcandles in the areas used by checkers who make a detailed count of kinds and numbers of milk bottles being loaded or unloaded. Industrial-type, direct-lighting equipment is suitable.

Table 10-16. Recommended Maintained Minimum Illumination Levels for the Fluid Milk Industry

LOCATION	FOOTCANDLES MAINTAINED IN SERVICE*	FOOTLAMBERTS
Boilers	10	—
Bottle storage	10	—
Bottle sorting	50	—
Bottle washers	—	250†
Cap washers	20	—
Cleaning fittings and pipes	—	200‡
Cooling equipment	20	—
Filling and inspection	50	—
Gauges	30 on facet	—
Laboratories	50	—
Loading platforms	10	—
Meter panels	30 on facet	—
Pasteurizers	20	—
Receiving room	20	—
Scales	30	—
Separators	20	—
Storage refrigerator	10	—
Tanks	—	5
Thermometers	30 on facet	—
Vats	50†	—
Weighing room	10	—

* These footcandle values represent order of magnitude rather than exact levels of illumination.
† See text for explanatory details.
‡ Brightness of luminous area toward which the workman sights through pipe.

Bottle-Storage Rooms

In bottle-storage rooms it is necessary to pick out foreign articles, remove caps, sort out very dirty and foreign bottles, and to sort and segregate various types such as retail and store bottles. A minimum illumination level of 50 footcandles should be maintained throughout sorting areas. A uniform illumination level of 10 footcandles is recommended for the remaining portion of the bottle-storage room.

Bottle Washers

One of the most difficult problems in a modern dairy is to light milk bottles as they are discharged from a bottle-washing machine so that foreign matter, fractures, etc., are quickly and easily seen.

Method of operation. The complete operating cycle of a typical bottle-washing machine lasts 6 seconds. The clean bottles stand still (up-ended) for $1\frac{1}{2}$ seconds in full view of the operator, at a distance of 40 inches. During this time (0.2 second per bottle) he inspects them while picking up a load of dirty bottles. If the dirty bottles do not require his attention, he may have a fraction of the remaining $4\frac{1}{2}$ seconds to inspect some of the clean ones as they move out. General illumination of not less than 20 footcandles should be provided, supplemented with a minimum of 50 footcandles of well-diffused light at the loading end of the washer.

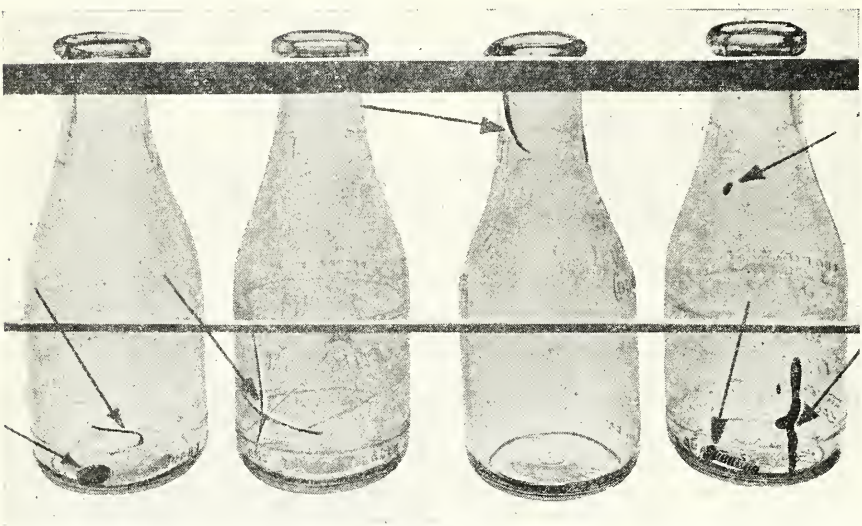


FIG. 10-99. Closeup of bottles lighted by luminous inspection panel. Bottles may be inspected efficiently for foreign matter, and fractures are made easy to see.

Inspection. Bottles are inspected both while being placed in the washer and after discharge from the washer. The purpose of the inspection is to discard foreign or store bottles; bottles stained beyond recovery; bottles with chipped necks or cracks; and incompletely washed bottles. Foreign bodies such as paper caps, wire, and nails must be removed.

It was found experimentally that inspection of bottles silhouetted against a low-brightness luminous surface as in Fig. 10-99 is the most efficient method. A luminous inspection panel may be incorporated in the unloading mechanism in the form of an inspection light-box. A typical box consists of a sheet-metal enclosure containing lamps and auxiliary equipment, the open front of which is covered with a translucent plastic sheet. The assembly is placed in the unloading mechanism in such a way that when the bottles are pushed out of the washer they are silhouetted against the luminous panel. Incomplete washing, cracks, chips, foreign matter in the bottles, etc., can be detected readily. (See also Fig. 10-100.)

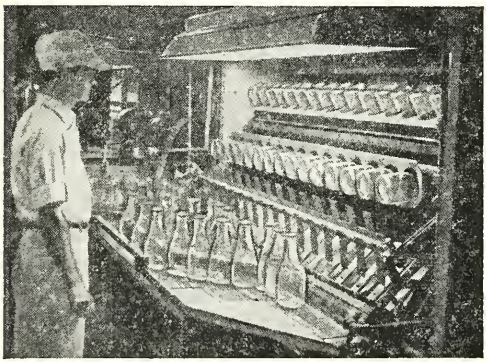


FIG. 10-100. Illumination of bottle washers which cannot be modified to accommodate a luminous panel may be improved by installing a large-area luminaire directly above the inspection end.

A maximum brightness of 500 footlamberts is permissible with 250 footlamberts the preferred value.

Manufacturing Areas

General lighting equipment in a fluid milk plant should provide an illumination level of at least 20 footcandles. The light should be well diffused. Rooms should be finished with ceiling reflectance of 75 per cent or more and with side-wall reflectance of from 50 to 60 per cent.

The lighting should be such that there will be no specular images of the light sources formed on the surface of a bottle, whether empty or full, that will interfere with the proper inspection of the bottle or the finished product. The distribution characteristics and spacing of luminaires should be such that no sharp shadows will be cast. Areas adjacent to walls or corners should not fall below an illumination level of at least 10 footcandles.

REFERENCES

To supplement the condensed Handbook treatment, the Recommended Practices of the Illuminating Engineering Society listed on page 10-28 and many papers in the Transactions of the Illuminating Engineering Society (through 1939) and in Illuminating Engineering (1940 and later) including the following taken primarily from those appearing between 1937 and 1947, will be found helpful. Details of outstanding lighting installations in various fields will be found in current I.E S. Lighting Data Sheets.

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SECTION 11

EXTERIOR LIGHTING

Exterior-lighting applications discussed in this section are various types of electrical advertising and decoration, including signs, luminous commercial fronts, and floodlighting. Lighting for gardens, pools, fountains and waterfalls and for the prevention of sabotage, theft, and accident also is discussed.

Illumination for outdoor sports is covered in Section 12, and Section 13 describes current lighting practice for transportation areas, including streets and highways, railroads, and airports.

LIGHTING FOR ADVERTISING

Electrical advertising in the United States dates from the latter part of the nineteenth century and since that time has become one of the strong mediums of the art. It is used for several purposes, including:

Identifying a place of business
Advertising a building or plant
Advertising a product or a service

Electrical advertising differs in several respects from other major classes of advertising such as printed matter and radio. In the case of printed matter (newspaper, magazine, and direct-mail advertising), the reader handles the copy which attracts his attention. No time limit is imposed on the reader's perusal, and printed characters are planned to contrast well with their background. Radio advertising appeals to a listener through his hearing sense, after attracting his attention.

Electrical-sign advertising, on the other hand, to be successful in terms of present-day business economics, should gain the observer's attention and serve its purpose in the relatively short period of a few seconds.

ELECTRIC-SIGN CHARACTERISTICS

Outdoor electric signs may be classified as follows:

1. Exposed incandescent lamp signs.
2. Enclosed lamp signs.
3. Silhouette signs.
4. Electric-discharge lamp signs.
5. Combination signs (incandescent and discharge lamps).
6. Poster panels, panel signs, and wall signs.

They may be evaluated from two interrelated approaches: *legibility* and *advertising effectiveness.*

Size. Physical location, desired legibility range, and character brightness determine the minimum letter height required for legibilty. However, to attain advertising effectiveness, letter heights of twice minimum height generally are employed for legibility. Vertical columns of letters, though usually an aid in increasing the apparent size of a sign, are more difficult to read than horizontal columns.

NOTE: References are listed at the end of each section

Brightness. Letter brightness and contrast between letter and background are factors influencing the legibility of a letter and the rapidity with which it is recognized. Contrast between the average sign brightness and that of its background determines, in a large measure, the manner in which the sign stands out. Brightness and contrast attract attention.

Location and position. The advertising value of a sign depends on the greatest possible number of persons seeing it. This is a function of its location.

Distinctiveness. One of the elements of a good electric sign is that it possess distinctiveness and individuality. It should create a pleasing, favorable impression, should have public appeal, and should be remembered easily.

Motion. Motion increases the attracting power and memory value of a sign. It capitalizes on the instinctive trait of people to be aware of and to give heed to moving things.

Color. Often color is incorporated in a sign because (1) it provides contrast and therefore is an important factor in legibility, (2) it may aid in attracting attention, and (3) it may add distinctiveness.

Exposed Incandescent Lamp Signs

These signs are constructed so that the lamps are exposed to direct view. This type is well suited for application where long viewing distances are involved. Motion and color can be incorporated very easily in such signs. An outstanding example of the exposed lamp sign is shown in Fig. 11-1.



FIG. 11-1. This spectacular exposed lamp sign in Times Square, New York City, is over a city block long. Approximately 30,000 lamps are flashed in sequence to suggest motion of the figures in the display.

Channels (Fig. 11-2) used on exposed lamp signs comprise a background on which a succession of lamp sockets are fastened between sides which outline a letter. The sides prevent lamps from illuminating the adjacent area. Thus they help to maintain contrast between letter and background. Also, they prevent one portion of the sign from interfering with the legibility of another portion, outline the letters for improved daytime legibility, and increase brightness uniformity.

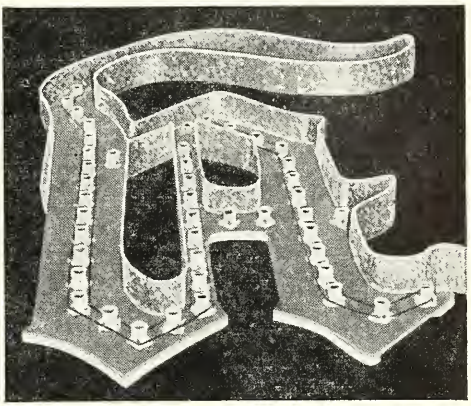


FIG. 11-2. Letter channels carry lamp sockets and by restricting the spilled light from the background increase contrast between letter and background.

Effective range. The range of advertising effectiveness of exposed lamp signs is from 250 feet to several miles.

Legibility. Legibility is primarily a function of letter size and form or design, lamp spacing and brightness, and contrast between letter or design and background.

Block letters possess greater legibility than do ornamental styles, script, and special forms, although the latter types may be used to gain distinctiveness. Wide, extended letters are more legible than tall, thin letters.

Letter size. The minimum letter height employed on an exposed lamp sign usually is greater than the height necessary to gain recognition. For purposes of advertising and quick reading, it is common practice to provide exposed lamp signs with letter heights that are at least twice those necessary for recognition.

For simple block letters (the width equal to three-fifths of the height) the minimum letter height for advertising and quick reading purposes is given by the formula:

$$H_a = \frac{R}{250}$$

where H_a = vertical height of letter, for advertising and quick reading, from top lamp to bottom lamp (feet)

R = maximum range of sign for advertising effectiveness (feet)

Smaller letters will have less advertising value, but they will be legible to most people if their height is not much less than that given by the formula:

$$H_r = \frac{D}{500}$$

where H_r = minimum vertical height of letter for recognition from top lamp to bottom lamp (feet)

D = maximum distance at which letter is recognized by majority of people (feet)

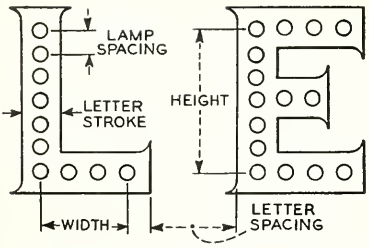


FIG. 11-3. Important dimensions in the design of exposed lamp letters.

Letter width, height, stroke, and spacing, and lamp spacing are illustrated in Fig. 11-3. (See Table 11-1, also.)

Lamp spacing. The proper spacing between lamps that comprise a letter is determined by the minimum viewing distance.

Spacing may be calculated by the following formula:

$$s = \frac{MVD}{1{,}000}$$

where s = spacing between centerlines of lamps (feet)

MVD = minimum viewing distance (feet)

Lamp wattage rating. The incandescent lamp wattage employed depends upon the general brightness of surroundings, and background, as the sign is viewed. Consequently, a roof sign, even if located in a brightly lighted area in the business center of a city, might at night always be viewed against a dark sky. Such a sign would require the same lamps called for in an outlying dark district.

Table 11-2 indicates the proper spacing and wattage of clear lamps for exposed lamp signs located in different areas classified according to the probable brightness of a sign's background.

Table 11-1. Dimensions of Exposed Lamp Letters for Equal Advertising Effectiveness at Different Ranges

EFFECTIVE RANGE (feet)	MAXIMUM DISTANCE LEGIBLE (feet)	DIMENSIONS (inches)			LETTER SPACING (inches)
		Height	Width	Stroke	
200	400	10	6	2.5	4
250	500	12	7	2.5	4.75
300	600	14	8	2.5	5.5
350	700	17	9.5	2.75	6.5
400	800	19	11	3	7.5
450	900	21.5	12.5	3.5	8.5
500	1,000	24	14	4	9.5
750	1,500	36	26	5	14.5
1,000	2,000	48	29	6	19
1,500	3,000	72	43	9	20
2,000	4,000	96	58	12	38
2,500	5,000	120	72	15	48
3,000	6,000	144	86	18	58
3,500	7,000	168	100	21	68
4,000	8,000	192	115	24	77
4,500	9,000	216	130	28	87
5,000	10,000	240	144	30	96

Table 11-2. Lamp Spacing and Lamp Wattage for Exposed Incandescent Lamp Signs

BACKGROUND BRIGHTNESS		LETTER HEIGHT (inches)								LETTER HEIGHT (feet)															
		10		14		19		24		3		4		6		8		10		12		16		20	
		S = Lamp Spacing (inches)								W = Lamp Rating (watts)															
		S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W
Brightest (Times Sq. New York)		2½	15	2½	15	3	25	3	25	3	25	3½	25	3½	50	4	50	4	50	8	50	10	60	12	100
Other Large City Squares		2½	15	2½	15	3	25	3	25	3	25	3½	25	3½	25	4	50	4	50	9	50	11	50	13	60
Most City Squares	Bright	2½	15	2½	15	3	15	3	25	3	25	3½	25	3½	25	4	25	4½	50	10	50	12	50	14	60
	Medium	2½	15	2½	15	3	15	3	15	3	15	3½	25	3½	25	5	25	5	25	10	25	12	50	15	50
	Dim	2½	15	2½	15	3	15	3	15	3	15	3½	15	4	25	5	25	6	25	11	25	13	25	15	50
Business Sections	Bright	2½	10	3	15	3	15	3	15	3	15	4	15	4	15	6	15	7	25	12	25	14	25	18	25
	Medium	3	10	3	15	3	15	3	15	3	15	4	15	4½	15	7	15	7½	15	12	25	15	25	18	25
	Dim	3	10	3	10	3½	15	3½	15	3½	15	4	15	5	15	7½	15	8	15	13	15	16	25	20	25
Small Cities and Large Towns		3	10	3	10	3½	10	3½	10	3½	15	4½	15	5½	15	8	15	9	15	14	15	17	15	20	25
Dark Factory Districts		3	10	3	10	3½	10	3½	10	3½	10	4½	15	6	15	8	15	10	15	15	15	18	15	24	15

If incandescent lamps with colored glass bulbs or clear bulbs with colored accessories are employed, lower letter brightness will result than when equal wattage lamps with clear bulbs are used alone.

For equal advertising effectiveness colored surfaces require less brightness than neutral surfaces as shown in Table 11-3.

Table 11-3. Relative Wattage of Colored and White or Inside Frosted Incandescent Lamps Required to Give Signs of Various Colors Approximately Equal Advertising Value

COLORED LAMP RATING* (watts)	WHITE OR INSIDE FROSTED LAMP RATING (watts)					
	Daylight Blue†	Yellow†	Amber-Orange†	Green†	Red†	Blue†
10	15	10	10	25	25	50
15	15	10	10	25	25	50
25	25	25	25	50	50	50
40	50	50	50	50	60	60
60	60	60	60	100	100	150
100	100	100	100	150	150	200

* Color similar to that of sign surface; 100-watt or larger lamps require color hoods.
† Color of sign surface and lamp to which white or inside frost rating compares.

Lamp types. For exposed lamp signs located where rain or snow could fall on relatively hot glass, vacuum-type incandescent lamps are recommended. They are available in 6-, 10-, 25-, and 40-watt ratings in both clear and colored bulbs, and in 25- and 50-watt ratings in daylight bulbs. Inside-coated or colored-bulb lamps are recommended in exposed lamp signs, since their color is more stable than that of outside coated lamps.

Reflector signs. Efficient reflectors can be employed to direct light to areas in which it is most useful and create letter brightnesses several times that of a corresponding letter without reflectors.

Typical polished reflector equipment is shown in Fig. 11-4a and a complete letter using such equipment is shown in Fig. 11-4b. The reflecting device consists of a small polished reflector with a medium-screw base that will fit into standard sockets. This reflector uses a 3-, 6-, or 7-watt, candelabra- or a 6- or 10-watt, intermediate-base lamp. Either clear or colored glass roundels in prismatic designs are placed over the reflector opening. Where excellent side-angle brightness is a requirement, cover glasses should be employed. For equal advertising value over a limited area in certain directions, polished reflectors, if used, may result in a rebuction in required wattage as great as 75 per cent.

Enclosed Lamp and Silhouette Signs

Enclosed lamp signs employ light sources enclosed with glass, plastic, or other light-transmitting materials. The letters or designs usually are opaque but may be etched in light-transmitting material.

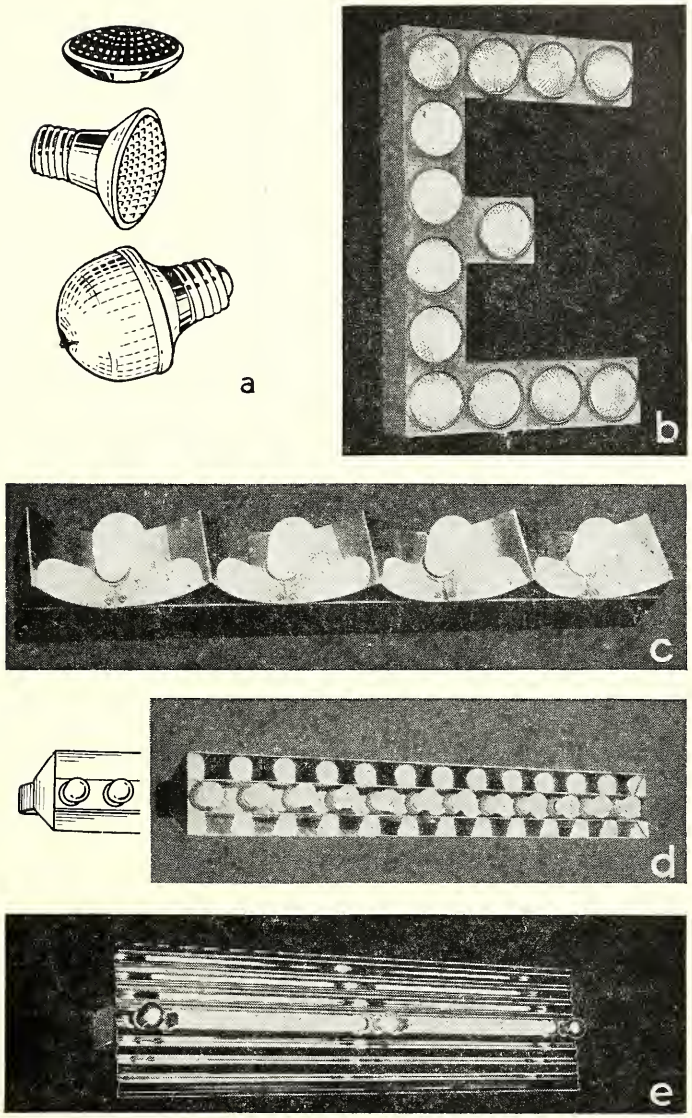


FIG. 11-4. a. Typical polished reflectors and cover glasses for sign lamps. b. Sign letter with polished reflectors and cover glasses installed. c. Parabolic reflectors such as these appear as a continuous line of light when the lamps are operating. d. When operated in a specular trough reflector such as this, a single row of lamps appears as three rows. e. A specular reflector of corrugated cross section forms many source images and spreads them in a broad pattern over its surface.

Silhouette signs are those in which opaque letters, designs, etc., are located in front of a luminous background and appear in silhouette against it. Figure 11-5 shows typical silhouette signs.

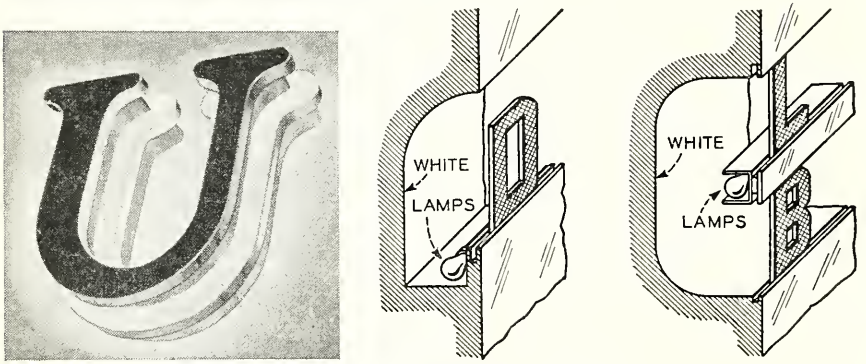


FIG. 11-5. Typical silhouette sign construction.

Effective range. Enclosed lamp and silhouette signs do not have as great effective range as similar exposed lamp signs because contrast between letters or designs and background is reduced by loss of brightness in the enclosures.

The maximum range of effectiveness for advertising purposes of enclosed lamp and silhouette signs is approximately 1,000 feet.

Etched letters. The sign characters are etched on the light-transmiting medium which may be translucent marble, ceramic glass, plastic, etc.

Painted letiers. Letters are painted on the light-transmitting medium. This type is economical from the standpoint of first cost. Peeling with age may be a maintenance difficulty.

Metal letters. Many styles of cast metal letters are available. This type may be changed quickly and easily.



FIG. 11-6. Effect of letter design on legibility at an angle.

Block letters. The block type of letter is used commonly where side-angle effectiveness is important. (See Fig. 11-6.)

Translucent letters. With colored light sources behind it, this type of letter makes possible changes in color.

Bi-plane letters. This type is constructed of two simple channeled letters, one in front of the other. Behind each letter, light sources illuminate its background. (See Fig. 11-5.)

Legibility. In general, block letters are recognized as being more effective than flat, thin letters or script, although use of the latter types should not be precluded as they may aid in the achievement of individuality. Wide extended letters are more legible than narrow, condensed ones.

Letter size. Letter legibility is a function of the ratio of stroke width to letter height. Figure 11-7 shows this relationship for any given letter height. The most favorable proportion is 0.15. This does not mean that other proportions should be disregarded. Individuality and distinctiveness are achieved through the use of other proportions. Also, the desired viewing distance for many signs is much less than the maximum legibility distance for the patterns employed.

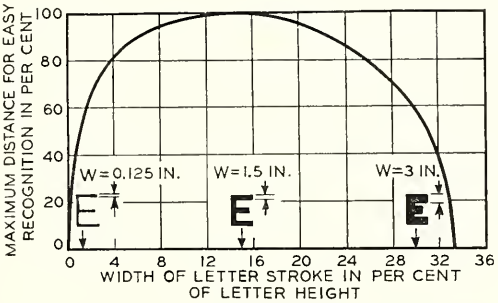


FIG. 11-7. Effect of stroke on easy recognition distance of an opaque block letter on a luminous background. Test object (10 inch x 7 inch letter E) was viewed against a 72 inch x 35 inch luminous panel erected on a dark street. Scattered lights were visible in the field of view, also.

For block letters of a width equal to three-fifths of the height and a ratio of stroke to height of 0.15, the minimum letter height is given by the formula:

$$H_a = \frac{R}{440}$$

where H_a = minimum letter height for advertising and quick reading (feet)

R = maximum range of advertising effectiveness of sign (feet)

Smaller letters will have less advertising value, but will be recognized readily if their heights are not less than the values determined by the formula:

$$H_r = \frac{D}{660}$$

where H_r = vertical stroke height of letter for ready recognition (feet)

D = maximum distance at which letter is readily recognized (feet)

For ratios other than 0.15, the maximum distance, D, for ready recognition, is shown in Fig. 11-8.

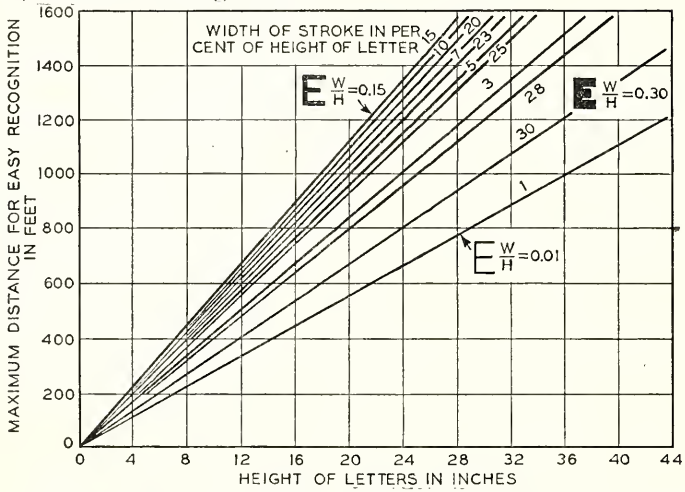


FIG. 11-8. Effect of height on easy recognition distance of an opaque block letter on a luminous background for various stroke per height ratios. The test object (10 inch x 7 inch letter E) was viewed against a 72 inch x 35 inch panel with brightness of 120 footlamberts under the same conditions as in Fig. 11-7. To obtain distance values for other panel brightnesses, multiply the value from this graph corresponding to the proper letter size by the distance factor obtained from Fig. 11-9.

Brightness and size of illuminated background also affect the maximum distance at which a sign is effective and readily recognizable. Curves showing the effect of luminous area on distance for ready recognition are given in Fig. 11-9. In determining luminous area, deductions should be made for the area obstructed by the letters.

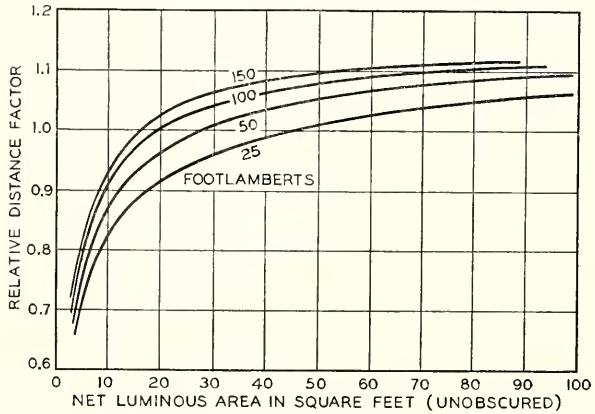


FIG. 11-9. Effect of a partially obscured luminous background area on easy recognition distance for an opaque block letter viewed against it. Unity on the relative distance scale corresponds to 552 feet for a test object (10 inch high letter E, 1.5 inch stroke) viewed against a panel of the same size and brightness as in Fig. 11-8. To obtain maximum ready recognition distance for a letter of another size, obtain the value for a letter of that size from Fig. 11-8 and multiply that value by the distance factor.

Sign brightness. For equal advertising effect, the luminous element brightness of an enclosed lamp sign will vary with the brightness of the surroundings that form its background. Recommended brightnesses for a variety of signs and other objects are given in Table 11-4 for low-, medium-, and high-brightness backgrounds.

Table 11-4. Recommended Brightness for Exterior Luminous Signs and Elements*

EXTERIOR ELEMENT	RECOMMENDED BRIGHTNESS (footlamberts) Average Brightness of District		
	Low	Medium	High
Luminous-background signs	90 to 150	120 to 200	150 to 350
Luminous-letter sign	150 to 200	200 to 400	300 to 600
Flush elements:			
Fascia signs	30 to 100	50 to 150	100 to 300
Panels	30 to 100	50 to 150	100 to 300
Parapets	30 to 100	50 to 150	100 to 300
Recesses	30 to 100	50 to 150	100 to 300
Principle units in design	30 to 100	50 to 150	100 to 300
Subordinate elements in design	10 to 50	35 to 80	50 to 150
Spandrels	10 to 50	35 to 80	50 to 150
Projecting elements:			
Pylons	30 to 100	70 to 150	100 to 300
Free-standing columns	30 to 100	70 to 150	100 to 300
Dominant	30 to 100	70 to 150	100 to 300
Subordinate	30 to 60	40 to 80	50 to 150
Marquee and entrance (soffits, marquee fascias, luminous beams)	80 to 150	100 to 250	200 to 400
Small luminous façades	80 to 120	100 to 150	120 to 200

* These values do not apply for colored light. Where colored light is employed, field tests are recommended.

Wedge Signs

A wedge sign is a double-faced, stick-out type of sign, as indicated in Fig. 11-10. With lamps placed in a parabolic trough reflector at the wall side of the wedge, acceptable brightness uniformity of the translucent side panels results when panels are sloped at an angle of approximately 18 degrees.

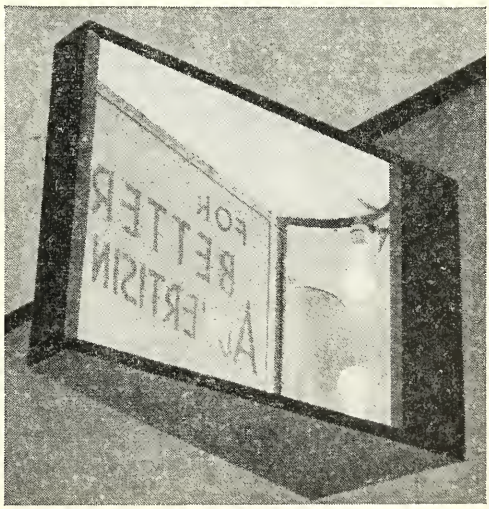


FIG. 11-10. Wedge sign with one face removed to show lamps and reflector.

Fascia Signs

A fascia sign comprises a reflecting cavity in which light sources are placed behind an exposed facing of translucent material. Figure 11-11 shows a schematic diagram of typical fascia signs with the more important dimensions noted for design purposes.

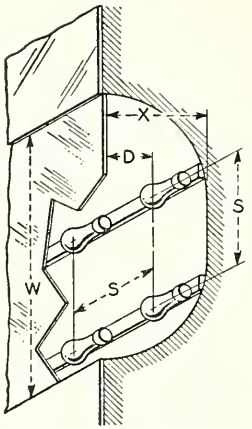


FIG. 11-11. Typical fascia sign construction showing important design dimensions.

In general, the maximum desirable ratio of width (per row of lamps) to depth of cavity is 1.5. Greater ratios tend to decrease the efficiency of the sign element and do not permit maximum desirable lamp spacing.

Any cavity with sharp rectangular corners traps light; hence, its use is to be discouraged.

Cavities should be finished with a durable, high-reflectance surface. In case the reflecting background is subjected to wearing by the elements, porcelain-enameled metal or the equivalent is recommended because of its permanence and mat finish. Glossy finishes reflect images of the lamps which tend to interfere with legibility.

For uniform panel brightness in the case of opal glass or translucent material with equivalent diffusion characteristics, lamps should be spaced on centers not in excess of $1\frac{1}{2}$ times the light center distance behind the translucent material.

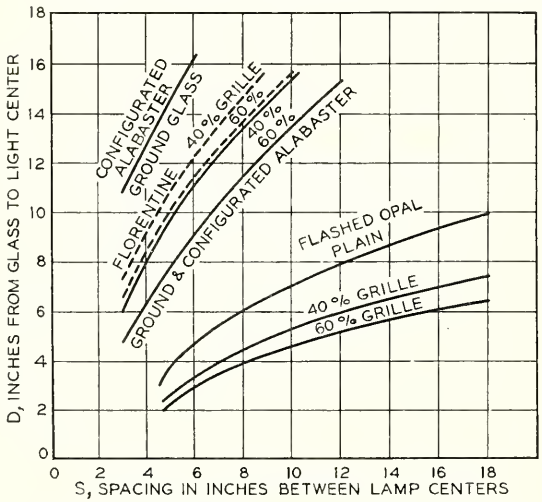


FIG. 11-12. Effect of spacing between lamp centers on the minimum distance between lamp and panel which will produce acceptable brightness uniformity, for several panel materials.

Figure 11-12 indicates the maximum permissible spacing between lamp centers to produce acceptable panel brightness uniformity for several types of diffusing glass.

The average brightness of the district in which a fascia sign is located influences the sign brightness. Recommended brightness values are given in Table 11-4.

Table 11-5 gives the average brightness of opal glass panels covering one, two, and three rows of incandescent lamps, respectively, for different lamp wattages and for various relationships of cavity size and lamp spacings.

Table 11-5. Brightness Data for Fascia Signs or Panels

DIMENSIONS* (inches)				AVERAGE BRIGHTNESS DESIRED (footlamberts)					
				50	100	150	200	300	400
W	X	D	S	Wattage Rating of Incandescent Lamps Required (one row)					
4	4	2.5	4	—	—	6	6	10	10
6	6	4	6	—	6–10	10	15	15	25
9	8	6	9	10	15	25	25	40	40
12	10	8	12	15	25	25–40	40	50	60
18	15	12	18	25	40	60	75	100	150
24	19	16	24	40	60	100	100	150	200
30	23	20	30	60	100	150	150	200	300
36	28	24	36	75	150	200	200	300	300–500
48	37	32	48	100	200	300	300	500	750
				Wattage Rating of Incandescent Lamps Required (two rows)					
18	8	6	9	10	15	15–25	25	40	40–50
24	11	8	12	15	25	25–40	40	50–60	60–75
30	13	10	15	15–25	40	40–50	60	75	100
36	15	12	18	25	40–50	60	75	100	100–150
48	20	16	24	40	60–75	100	100	150–200	200
60	25	20	30	50–60	100	150	150–200	200–300	300
72	30	24	36	75	150	200	200	300	300–500
84	35	28	42	100	150	200	300	500	500
96	40	32	48	100	200	300	300–500	500	750
				Wattage Rating of Incandescent Lamps Required (three rows)					
30	11	8	10	10	15	25	25–40	40	50
36	13	10	12	15	25	25–40	40	50–60	60–75
42	15	11	14	15	25–40	40	50	60–75	75
48	18	13	16	25	40	50	60	75	100
60	21	16	20	25–40	50	60–75	75	100	150
72	24	19	24	40	60–75	100	100–150	150	200
84	29	23	29	60	100	100–150	150	200	300
90	32	26	32	60	100	150	200	200–300	300

* See Fig. 11-11.

Illuminated Block Letter Signs

Illuminated block letters are suitable for use at low mounting heights. Each letter of this type of sign is an indivilual closed lamp sign for which data is given on Page 11-6.

Electric Discharge Lamp Signs

An electric discharge lamp sign usually is an exposed lamp type of sign since, in practically all cases, such signs utilize unshielded tubing. Tube signs are constructed of gas-filled glass tubing which, when subjected to high voltage, becomes luminescent in a color characteristic of the particular gas used or of the fluorescent phosphors coated on its inner wall.

Fluorescent tubing may be made to emit almost any desired color by mixing different phosphors. Most colors have a higher lumen output-per-watt rating than the gaseous tubing without a fluorescent coating.

Color. Color produced by any one of these gases may be modified by using colored glass tubing, which will transmit only certain colors.

Gases employed. Table 11-6 lists some of the gases which may be used and the color of light produced by each.

A typical tube sign and its wiring are shown in Fig. 11-13.

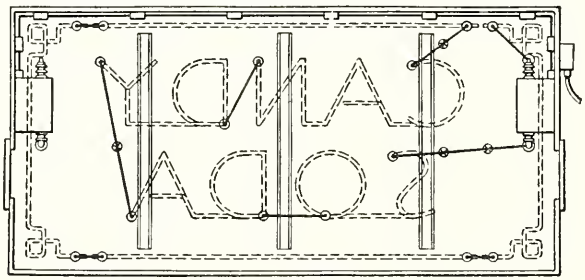


FIG. 11-13. Typical tube sign wiring.

Effective range. The range of effectiveness for advertising purposes of tube signs is approximately the same as that of exposed lamp signs of the same size, color, and brightness: 250 feet to several miles.

Legibility. For block letters of a width equal to three-fifths of their height, the minimum letter height that will be legible to most people at given distances is stated in Table 11-7, for red tubing. When colors other than red are employed, distances given in Table 11-7 should be reduced. The necessary reduction in the case of blue tubing is 25 per cent; in the case of green tubing, it is 35 per cent.

For a given letter height, the corresponding letter and stroke width may be determined from those proportions given in Table 11-1, page 11-4.

Tubing sizes. Standard sizes of tubing for signs range from 9 to 15 millimeters, outside diameter, but larger tubing is available.

Transformers. Several forms of high-leakage-reactance type transformers are manufactured to supply the high voltage necessary to start and operate sign tubing. This voltage is of the order of 5,000 to 15,000 volts. After a tube sign is lighted, one-third to one-half of the starting voltage is necessary to keep it operating. The usual range of operating current for tube signs is between 10 and 50 milliamperes.

Table 11-8 gives the maximum lengths of tubing which may be operated satisfactorily on various transformers. The values given represent the average of data published by several manufacturers.

Table 11-6. Gases Which May be Employed in Sign Tubing and Their Characteristic Colors

GAS	CHARACTERISTIC COLOR	GAS	CHARACTERISTIC COLOR
Neon	Red	Xenon	Sky blue
Argon	Blue	Carbon dioxide	White
Helium	Pinkish white	Mercury vapor	Blue green
Krypton	Lavender white		

Table 11-7. Maximum Distances at which Block Letters of Various Heights Are Legible to Most Observers when Illuminated by Neon (Red) Tubing

BLOCK LETTER HEIGHT (inches)	MAXIMUM DISTANCE FOR LEGIBILITY (feet)	BLOCK LETTER HEIGHT (inches)	MAXIMUM DISTANCE FOR LEGIBILITY (feet)
2	65	18	750
3	100	24	1,000
4	150	30	1,250
6	200	36	1,500
8	350	42	1,750
9	400	48	2,000
10	450	54	2,250
12	525	60	2,500
15	630	72	3,000

Winter operation. Winter temperatures may cause some difficulty in the operation of gaseous tube signs. In the case of mercury tubes, cold weather causes mercury condensation and this results in an appreciable reduction in light output. The brightness of mercury fluorescent tubes is so high that reduced light output may be acceptable. Where cold weather operation is the rule, higher mercury-vapor pressures may be used to offset the lower ambient temperature.

Neon fluorescent tubes are not subject to reduced efficiency in cold weather.

Poster Panels, Panel Signs, and Wall Signs

Poster panels and panel signs embrace that classification of signs in which the advertising message is illuminated by lamps in angle or floodlighting reflectors, located remotely from the sign's surface. Such signs usually are not effective at long range, but at relatively short distances they carry color and detail effectively.

Fundamental principles which should be followed in order to ensure an efficient and effective panel sign are:

1. To provide uniform illumination over entire sign face. See Table 11-9.
2. To make the brightness of sign sufficient so that it will stand out in contrast with its immediate surroundings.
3. To permit neither direct nor reflected glare.
4. To make the lighting equipment inconspicuous. It should be located so that it will not interfere with the view of the sign.

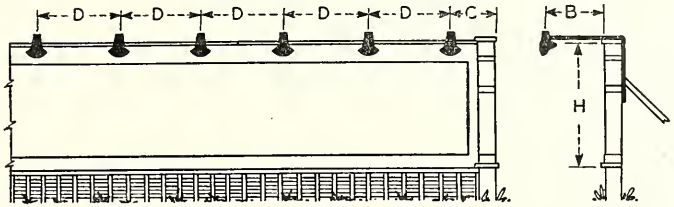
Table 11–8. Characteristics of Typical Transformers Used for Operating Luminous Tubing

SECONDARY VOLTAGE	SHORT CIRCUIT MILLIAMPERES*	VOLT AMPERE CAPACITY†	APPROXIMATE POWER CONSUMED AT 115 VOLTS, 60 CYCLES, (watts)	CLEAR OR FLUORESCENT RED AND NEON, FLUORESCENT GOLD												INDOOR CLEAR OR FLUORESCENT MERCURY TUBES (all colors)‡												OUTDOOR CLEAR OR FLUORESCENT MERCURY TUBES (all colors)§											
				Tube diameter (millimeters)												Tube diameter (millimeters)												Tube diameter (millimeters)											
				7	8	9	10	11	12	13	15	18	20	22	25	7	8	9	10	11	12	13	15	18	20	22	25	7	8	9	10	11	12	13	15	18	20	22	25
				Maximum length (feet) of Tubing Operable on One Transformer‖																																			
15,000	60	825	410	21	23	27	33	39	45	50	60	72	78	85	102	24	27	32	40	47	54	60	72	80	90	100	120	19	21	24	30	35	40	45	54	65	69	76	90
	30	450	225																																				
12,000	120	1440	560	16	18	21	25	30	35	39	45	55	61	67	79	18	21	25	30	36	42	46	55	62	70	79	95	14	16	19	22	27	31	36	40	49	55	60	71
	60	720	350																																				
	30	360	180	15	16	18	21	26	30	33	40					17	18	20	26	30	34	40	47					13	14	17	19	22	26	29	36				
	24	250	145																																				
9,000	120	1000	450	12	13	15	19	22	26	29	33	40	48	57	67	14	15	18	23	26	31	33	40	45	55	67	80	11	12	13	17	20	23	26	30	36	43	51	60
	60	500	240																																				
	30	250	125	10	11	13	15	18	22	24	28					11	13	16	18	22	26	29	34					9	10	11	13	18	20	22	25				
	18	190	100																																				
7,500	120	825	410	9	10	11	13	16	20	22	24	28	34	41	51	10	11	12	16	19	24	27	28	31	39	48	61	8	9	10	12	15	18	20	21	25	30	37	46
	60	450	210																																				
	30	225	110	8	9	10	12	14	18	20	22					9	10	11	13	17	21	23	25					7	8	9	11	13	16	18	19				
	18	150	75																																				
6,000	120	720	350	7	8	9	11	13	16	17	19	23	28	34	40	8	9	11	12	15	18	20	23	26	32	40	48	6	7	8	10	12	14	15	17	20	25	31	36
	60	360	170																																				
	30	180	75	5	6	7	9	10	14	15	17					6	7	8	11	12	16	17	20					4	5	6	8	9	12	14	15				
	18	140	60																																				
5,000	120	550	250	5	6	7	9	10	12	15	17	19	23	28	33	6	7	8	11	12	14	16	19	22	27	33	40	4	5	6	8	9	12	14	15	17	20	25	30
	60	300	140																																				
	30	150	70	5	5	6	7	8	11	13	14					6	6	7	8	10	13	15	17					4	4	5	6	7	10	12	13				
	18	100	45																																				
4,000	30	140	55	5	5	6	7	8	10	11	13	16	19	23	27	6	6	7	8	10	12	13	16	18	22	27	32	4	4	5	6	7	10	11	12	15	17	20	24
	18	90	40	4	4	5	6	7	9	10	11					5	5	6	7	8	11	12	13					3	3	4	5	6	8	9	10				
3,000	30	100	40	4	4	5	6	7	8	9	10	10	12	14	17	5	5	6	7	8	10	10	12	14	16	18	22	3	3	4	5	6	7	8	9	9	11	12	14
	18	75	30	3	3	4	4	5	6	7	8					3	4	5	5	6	7	8	10					2	3	4	4	5	6	6	7				
2,000	30	75	30	2	2	3	3	4	5	5	6					2	3	4	4	5	6	7	7					2	2	3	3	4	4	5	5				
	18	50	23																																				
Recommended gas pressures (millimeters of mercury)				18	17	15	13	12	11	10	9	8	7½	7	6	18	17	15	13	12	11	10	9	8	7½	7	6	18	17	15	13	12	11	10	9	8	7½	7	6

Note: For detailed discussion see "Correct Loading of Luminous Tube Transformers," *Engineering Service Release No. 4*, Acme Electric and Manufacturing Co., Cuba, N. Y.

* Tube operating current approximately 80 per cent of these values. † For approximate volt-ampere ratings of a high power factor transformer, multiply these values by 0.55. ‡ No. B-10, No. 50, and mercury vapor. These lengths apply also for outdoor installations if the temperature does not fall below 40 degrees Fahrenheit. § No. B-19, No. 20, and mercury vapor. ‖ Deduct 1 foot from above figures for each pair of electrodes; 25-cycle transformers will operate 87 per cent of indicated footage.

Table 11-9. Recommended Angle Reflector Spacing and Incandescent Lamp Wattage for Various Sizes of Signs



DIMENSIONS (feet)				LAMP WATTS*		
H	B	C	D	Dark Surround	Medium Surround	Bright Surround
2 to 4	2½	2½	5	50	75	100
5 to 6	3½	3	6	75	100	150
7 to 8	4	3½	6½	100	150	200
9 to 12	5	4	8	150	200	300
13 to 16	6½	5	10	200	300	500
17 to 21	9	6½	13	300	500	750
22 to 25	12	8½	17	500	750	1,000
25 to 30	15	10	20	750	1,000	—
11⅝ x 25†	5	4⅙	8⅓	150	200	300
12½ x 42‡	5¼	4⅓	8⅓	150	200	300
18 x 72§	8½	6	12	200	300	500

* For low-reflectance sign faces use the recommended lamp size for the next brighter surround.
† Standard poster panel. ‡ Standard City bulletin. *Note:* These spacings should not be exceeded, and closer spacing will result in a higher sign face brightness.
§ Railroad or highway bulletin.

COMMERCIAL FRONTS

Luminous fronts are incorporated in many commercial buildings for the primary purpose of creating an exterior appearance of maximum attraction. Such fronts incorporate luminous areas or elements arranged in such a manner as to increase the individuality of a structure. They provide a conservative and dignified way of achieving distinction, of advertising, and of attracting customers. (See Fig. 11-14.)

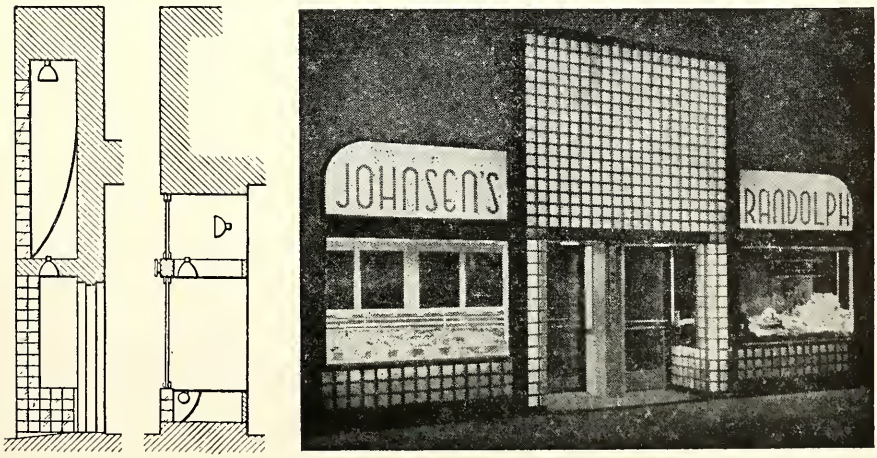


FIG. 11-14. Typical luminous front.

Commercial buildings may have their entire front luminous or have only certain areas luminous, such as fascia signs, panels, pilasters, or spandrels.

There is no limit to the variety and diversity of treatment which a luminous front may receive, particularly that type of front which employs transmitted light. Close co-operation between illuminating engineer and architect is recommended.

Luminous front design. Usually the design of a luminous front is a four-fold function. It concerns the show window, signs, and luminous elements.

The factors influencing the design of lighting for show windows are given on pages 10-73 to 10-74. Data on signs are given on pages 11-1 to 11-17.

The design of luminous elements concerns the characteristics of the materials to be made luminous with respect to the light control and light pattern which they afford, and also the characteristics of the applicable light sources. Formulas and tables will be found on page 8-34.

For the purpose of attracting maximum attention, it usually is desirable to have certain portions (fascia signs, important advertising areas, show windows, etc.) brightest so that these portions will retain their function of attracting customer attention.

For any given position of an element of constant size, the glare effect increases with its brightness. For this reason, extra care should be exercised in selecting the value of brightness for very large luminous areas. Large elements may have a lower brightness than smaller elements for equal advertising effectiveness.

Table 11-4 (page 11-11) gives recommended brightness values for a variety of signs and elements applicable in the design of luminous fronts.

The higher an element is above eye level, the brighter it must be for equal effectiveness. Luminous decorations at the top of a four-story building, for example, should be at least double the brightness of the same element located at eye level.

EXTERIOR FLOODLIGHTING

Outdoor areas may be floodlighted with utility, advertising, or decoration as the primary objective. Utility floodlighting such as for modern airports and similar areas is discussed in Section 13. Sports floodlighting is covered in Section 12. Floodlighting of public, commercial, and industrial buildings, monuments, museums, etc., covered here, usually is considered to be for advertising purposes. Floodlighting for decoration (advertising value may be associated with it) includes that of gardens, exhibitions, fairs, fountains, waterfalls, etc.

Floodlighting for decorative and advertising purposes is essentially an art rather than a science. No matter how carefully equipment is placed, unless it is properly adjusted after the installation is complete the results will not be satisfactory. When color is used it is frequently advisable to use a blend of colors in order to produce the desired effect.

Under certain conditions changing color has been used effectively. Such effects are most readily secured by using a dimmer on the white light to wash out the colored light gradually, at intervals.

Design Procedure

In designing floodlighting installations the following procedure may be used:

1. Determine the effect desired. Where the job is a large one, prepare an artist's conception of the completed job. The normal viewing location is important. For example, a building with projectors mounted on offsets and directed upward at a sharp angle may appear mediocre when viewed from ground level and yet be very attractive when viewed from an airplane. Good visibility from a train often is effective with national organization properties such as insurance company buildings.
2. Determine the location of the floodlights.
3. Determine the desired level of illumination. See Table 11-10.
4. Select the proper type of equipment.
5. Determine the required number and the lamp wattage rating of the floodlights.
6. Check the uniformity and coverage of lighting.

Formulas and tabular data are given on pages 25 and 8-26.

Table 11-10. Recommended Illumination Levels for Floodlighting

SURFACE MATERIAL	INITIAL REFLECTANCE (per cent)	SURROUND		
		Bright	Average	Dark
		footcandles		
White or cream terra cotta, white plaster, light marble	60–80	15	10	5
Light gray limestone, buff limestone, smooth buff face brick, tinted stucco	40–60	20	15	10
Briar Hill sandstone, smooth gray brick, medium gray limestone, common tan brick	20–40	30	20	15
Dark field gray brick, common red brick, brownstone, stained shingles	10–20	50	30	20
Poster panels and bulletin boards	Light Dark	50 100	35 75	20 50

APPLICATION	FOOTCANDLES	APPLICATION	FOOTCANDLES
Art glass windows	20–200	Waterfalls	10
Stained glass windows	30	Bridges	5
Signs	30	Monuments (see materials above)	
Smoke stacks with advertising	15	Trees	5–20
Flags	30	Water towers (light surfaces)	15–20

Note: Buildings or areas of materials having a reflectance of less than 20 per cent usually cannot be floodlighted economically unless they carry a large amount of high-reflectance trim.

Color in floodlighting. Colored light may be obtained by passing a floodlight beam through a glass, plastic, or gelatin filter. Glass and plastic filters are more stable and thus are better suited for permanent installation than gelatin filters. Gelatin filters are useful for short-term or temporary installations.

The transmittance of color filters usually falls within the following ranges: amber, 40 to 60 per cent; red, 15 to 20 per cent; green, 5 to 10 per cent; and blue 3 to 5 per cent. Table 11-11 indicates the factors by which incandescent lamp wattage must be increased when it is desired to provide *equal illumination in white and color. Relatively less colored light than white light is needed for equal advertising or decorative effect.* The second line of Table 11-11 gives factors by which clear-bulb incandescent lamp wattage must be multiplied in order to achieve an advertising or decorative effect in color equal to that obtained with a given wattage emitting white light.

Table 11-11. Approximate Factors by which Clear Bulb Incandescent Lamp Wattage Must Be Multiplied to Compensate for the Absorptance of Various Color Filters

DESIRED EFFECT RELATIVE TO CLEAR BULB	APPROXIMATE MULTIPLYING FACTOR			
	Amber	Red	Green	Blue
Equal illumination	2	6	15	25
Equal advertising or decoration	1.5	2	4	6

Floodlight cover glasses. A cover glass keeps dust, dirt, and moisture away from a floodlight reflector and lamp. Therefore, floodlights equipped with cover glasses need less frequent cleaning and the necessary maintenance is simplified. Figured cover glasses are available that modify the beam characteristics of a floodlight.

Floodlight lamps. Two types of incandescent lamps are used in floodlighting equipment, general service and floodlight lamps. Floodlight lamps that have concentrated filaments are used where narrow beams are desired. Hard glass lamps are recommended for open-type outdoor floodlights, and for other installations in which lamps may be exposed to water or moisture (a potential cause of breakage). Also, in enclosures where excessive temperatures prevail, hard glass bulbs will tend less to blister.

Mercury- and sodium-vapor lamps are limited to those installations in which color is not important. In some instances, mercury lamps may be used to advantage because of their distinctive bluish-green color; or used in combination with incandescent lamps since the average lumen-per-watt rating of a combination will be higher than that of incandescent lamps alone.

Because of their large size, light from fluorescent lamps can be projected only by very large reflectors. However, for floodlighting at close range, a fluorescent lamp can be used successfully. It is an efficient source of colored light.

Floodlighting of Buildings

Floodlighting of commercial and industrial buildings, public buildings, places of historical interest, power stations, etc., is a dignified means of advertising and identifying the structure and of indicating civic pride at nighttime. (See Figs. 11-15 and 11-16.)

In floodlighting a building, it is necessary that its form and beauty be neither distorted nor obscured and that the structure retain its identity. Buildings impress one not so much by their size or mass as by their beauty of outline and harmony of proportions.

The most appropriate type of floodlighting for a building depends upon its architecture and the effects to be achieved. In general, floodlighting should be such that the following five objectives are achieved:

1. Each surface should have such a brightness that it appears in proper perspective when viewed from afar. Floodlighting that flattens all surfaces and destroys perspective is undesirable. Also, large brightness differentials between adjacent areas of a building will distort appearance and cause the bright areas to appear closer to distant observers.

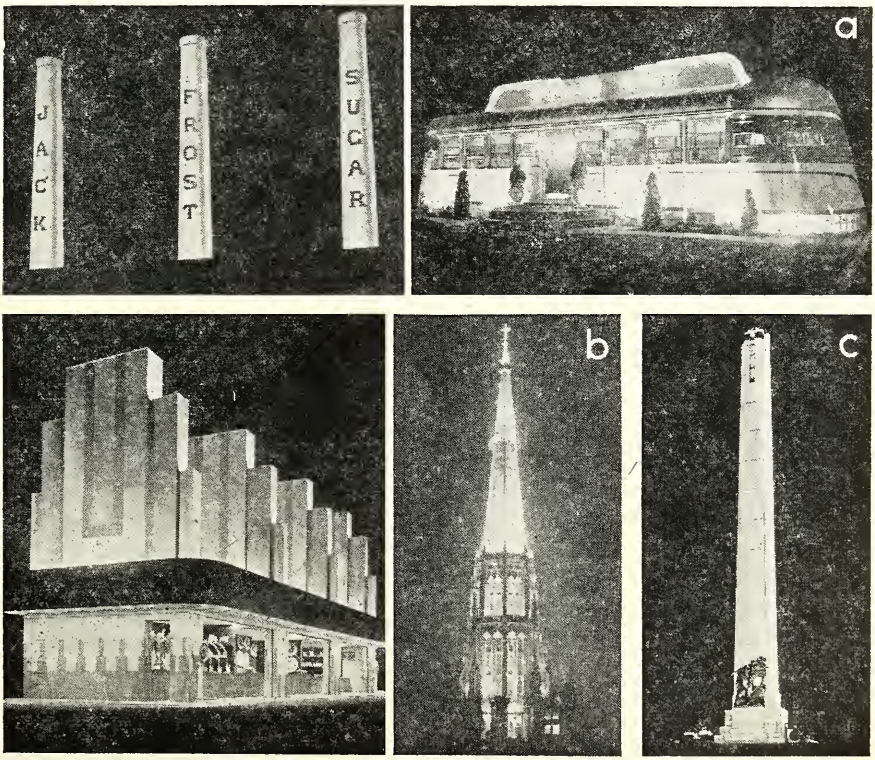


FIG. 11-15. Typical floodlighting installations may be installed to (a) advertise a product or owner, (b) identify a structure, (c) indicate civic pride.

2. Shadows cast should look like those cast by the sun. In those cases where a duplication of natural shadows cannot be effected, it is desirable that shadows present an interesting pattern. They should not destroy the basic form and depth of a building's architecture.

3. Walls and other flat surfaces should be illuminated to a level that will reveal their texture and character.

4. A building should be integrated with the area about it by illuminating sufficient surrounding area, in other words, a building should not appear suspended but rather oriented with adjacent grounds, slopes, stairs, plazas, etc.

5. Floodlighting equipment should be inconspicuously located and should not introduce glare in the field of view of persons normally observing the building.

The location of building floodlights depends upon local conditions. Ordinarily, four locations may be considered—on adjacent buildings, on adjacent ground, on the building itself, or on ornamental street standards. (See Fig. 11-16, also Fig. 8-3.)

Light spilled by improperly shielded and located floodlights mounted on adjacent buildings may annoy the occupants of those buildings. Changes in the adjacent buildings or in their ownership might necessitate a change in the installation. The need for independent metering often is a handicap to such an installation.

Floodlights located on the ground should be shielded with shrubs, bushes, etc., to make them inconspicuous and to shield observers' eyes from glare.

Many buildings have niches or ledges or marquees that will adequately accommodate floodlights. When these do not exist, it may be practicable to construct special balconies, canopies, or troughs to house the equipment. In the case of buildings with setback construction, floodlights may be located on the parapet at each setback.

Ornamental floodlights or lanterns may be mounted on street standards. These usually are equipped with two lamps—one lamp is used with an adjustable reflector for floodlighting and the other lamp illuminates the lantern and eliminates the black spot caused by the floodlighting reflector. An ornamental lantern presents a better daytime appearance than the ornamental floodlight but usually is limited in successful application to buildings not over three or four stories high.

Illumination level. Adequate illumination for any building is given in Table 11-10 for various surround brightnesses and building materials. Table 11-11 will be of assistance if color is to be used. If a building is located in an area which normally is crowded, it sometimes is advisable to reduce the brightness on the lower portion of the building to prevent possible annoyance to pedestrian and motor traffic. In the case of very tall buildings, where it is desirable to have an appearance of even brightness distribution over the entire surface, more illumination will be necessary on the higher portions of the building. (See page 8-25 for design calculation data.)

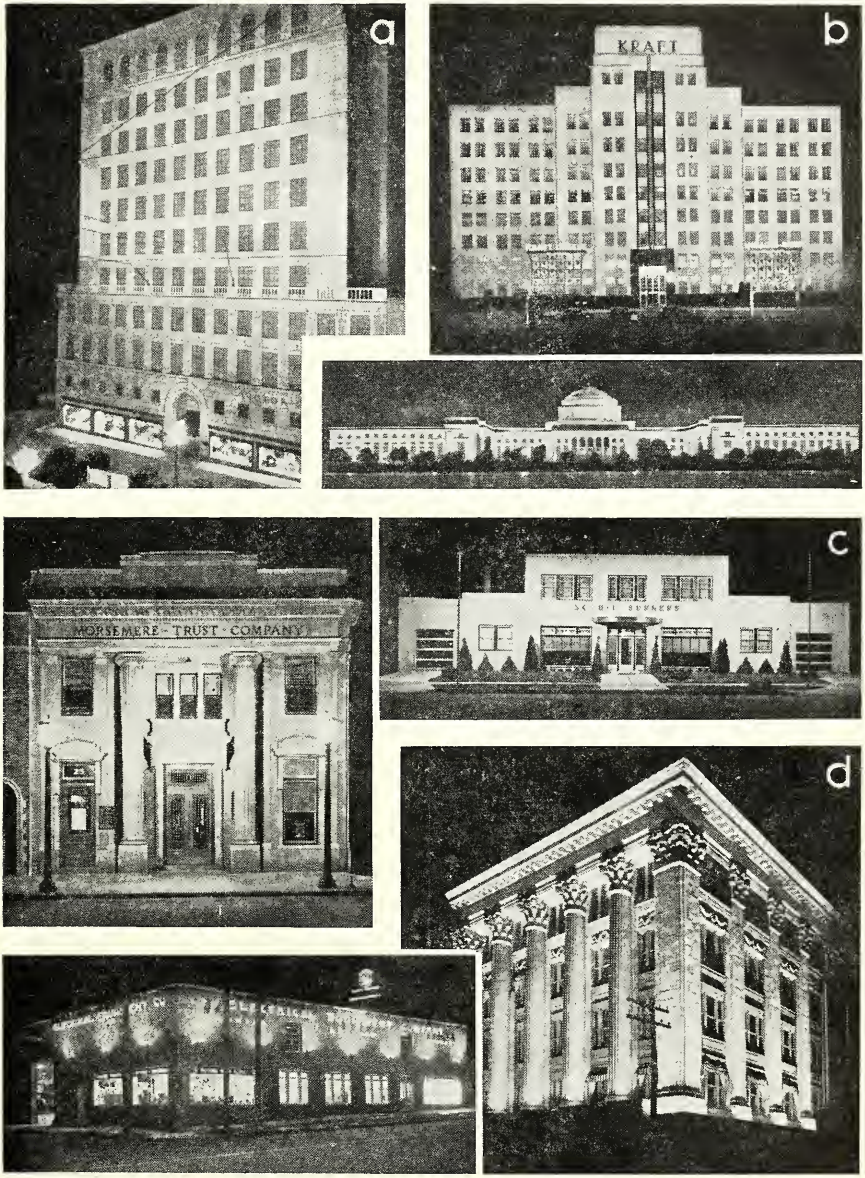


FIG. 11-16. Building floodlights may be mounted (a) on adjacent buildings,(b) on adjacent ground, (c) on street standards, (d) on the building to be lighted.

Column floodlighting. Two effective methods of lighting columns are shown in Fig. 11-17. Exposed floodlights may be objectionable when installed behind columns on the ceiling over entrances to buildings. In such cases effective silhouette lighting can be obtained through the use of recessed luminaires equipped with control elements designed to produce high illumination components on vertical surfaces.

When columns and background have the same brightness, the structure loses its form and the effect of depth.

Offset construction floodlighting. In general, uniformity of illumination of the entire wall area of setback construction is not desirable. Very attractive results may be accomplished if, as a whole, the building is more brightly illuminated as the height increases. The top portions of the building should be two to four times as bright as the lower portions in order to obtain apparent brightness uniformity and to add height to the building. (See Fig. 11-18.)



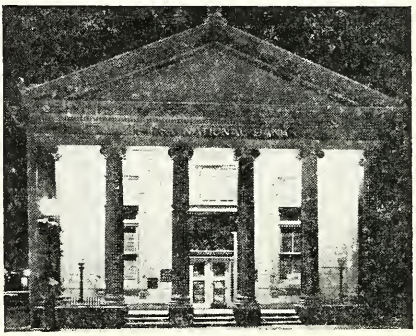
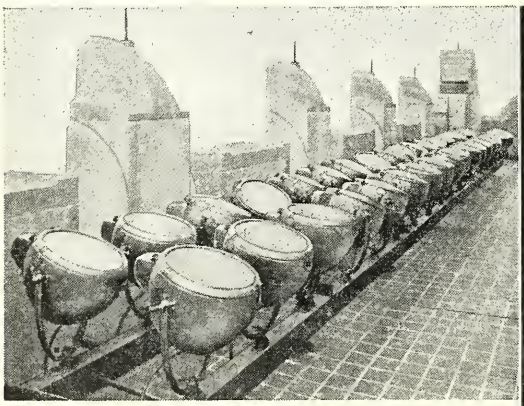


FIG. 11-17. Floodlighting of columns may be direct, as at left; or by silhouette, as in picture at right, which shows dark columns against a lighted background.



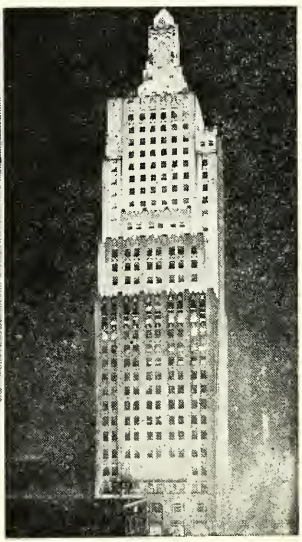


FIG. 11-18. The most attractive results in lighting tall buildings with setback construction are obtained when the top portions are two to four times as bright as the lower levels.

Floodlighting of setbacks should not destroy the form of the building, but rather it should make each setback appear in proper relationship with adjacent setbacks. A means of accomplishing this desirable result is to leave the upper portion of each setback comparatively darker than the lower portion of the next higher setback.

Floodlighting Monuments and Statues

The design of floodlighting for monuments and statues aims at the achievement of a natural lighted appearance. (See Fig. 11-19.) The relationship of shadows and brightness is of utmost importance. This is particularly true where the human form is concerned. When obelisk-type structures are lighted, depth can be maintained by adjusting the brightness of each face so that there will be a contrast between each pair in the field of an observer at any one time.



FIG. 11-19. This floodlighting installation for a free standing statue of a man properly duplicates the sculpture's daylight appearance.

GARDEN LIGHTING

In lighting gardens, composition, balance, color, and brightness should be considered. Also, in many instances, it should be remembered that observers may be in motion. Originality and novelty also are dominant factors. When lighting outdoor areas for decoration, it is not necessary to attain the natural daytime appearance that results from direct light from the sun mingled with diffused light from the sky. Many beautiful and unusual effects may be achieved by imaginative application of electrical illumination.

In the lighting of gardens the most common objectives are: (1) to illuminate objects which are centers of interest; (2) to illuminate water; (3) to illuminate outlines of opaque materials; and (4) to illuminate translucent objects.

General principles. Uniform floodlighting of garden areas usually is not satisfactory. Usually it is preferable to locate strategically several small lamps to obtain a delicately composed brightness pattern rather than a smaller number of higher output. Effect rather than efficiency is the primary objective. Uniformity of illumination is not necessary; in many

cases it is undesirable. Highlights and shadows produce a much more interesting and dramatic effect.

As a general rule, no light sources should be visible to an observer. Usually three choices of location are available: 1. Luminaires may be shielded from view by trees, shrubs, rocks, building structures, pits, etc; shrubbery may be planted expressly for this purpose. 2. Conventional equipment may be placed in a suitable housing with an appearance in keeping with that of the area. Some types of ornamental grilles around the lighting sources are satisfactory, particularly if they present a pleasing silhouette effect. In this case, the housings may be painted as an aid in camouflaging them during the daytime. 3. Equipment may be designed in keeping with the surround: mushroom shaped, for example, to fit into the general scheme of the garden.

Floodlights placed in trees or hedges may spill light on surrrounding branches and foliage which may create an undesirable effect. Therefore, small, more easily adjusted luminaires are to be preferred. In any event, shields, louvers, visors, or hoods to control spill light are recommended. Such control will make the equipment less conspicuous and there will be less chance of areas in the vicinity of the floodlight being illuminated unintentionally and disturbing the over-all effect.

Illumination level. As a rule, gardens are located where there is little competing illumination. High levels will create harsh and unpleasant effects. Levels which may be expected to give good results are recommended in Table 11-12.

Color. Considerable thought should be given to the application of colored light to gardens. Light from clear-bulb incandescent lamps is frequently undesirable as the high percentage of red and yellow light tends slightly to distort the delicate natural colors of flowers, shrubs, and trees found in gardens. Daylight lamps provide a color of light that is satisfactory in most cases. Blue light on some buildings, pergolas, etc., will simulate moonlight; yellow or amber light may be used effectively to light the surrounding area.

Table 11-12. Recommended Illumination Levels for Gardens

CENTER OF INTEREST	ILLUMINATION LEVEL (footcandles)
Statuary (white or colored)	0.5 to 1.0
Flower beds, rock gardens, etc.	0.2 to 0.4
Trees	0.2 to 0.4
Background (fences, trellises, walls, shrubbery)	0.1 to 0.2
Paths	*
Steps	†
Pond and pools (clear water)	‡
Fountains (single jet)	§

* 15-watt incandescent lamp every 20 to 25 feet.
† 15-watt incandescent lamp.
‡ 2 watts per square foot of water surface (incandescent lamps).
§ 15 watts per foot of height (incandescent lamps).

Pool, Fountain, and Waterfall Illumination

There are two methods commonly used for decorative lighting of pools and fountains. Still water acts as a mirror and will reflect clear images of lighted objects. When churned into spray and foam, water is an excellent diffuse reflector and will appear to absorb incident light and will change color to match that of the light.

A single jet fountain may be made attractive by installing directly beneath it, in a suitable water-tight enclosure, a spotlight directing its beam along the stream. Light from a near-by floodlight directed on the water is effective also. (See Fig. 11-20.)

In the case of large fountains which involve several jets, projector equipment may be located in the water and so directed that beams of light follow the water in motion. The effects which may be obtained by varying water flow, number of in-service jets, and colors of light are unlimited. In most instances, it is desirable to shield floodlights from view by installing over them an ornamental grille.

Colored lamps around the edge of a small pool or fish pond produce iridescence.

Cascades or rapidly moving brooks are fascinating to watch at night when they are floodlighted. Each little ripple and bit of foam sparkles with high brightness when illuminated by a beam tangent to the water surface.

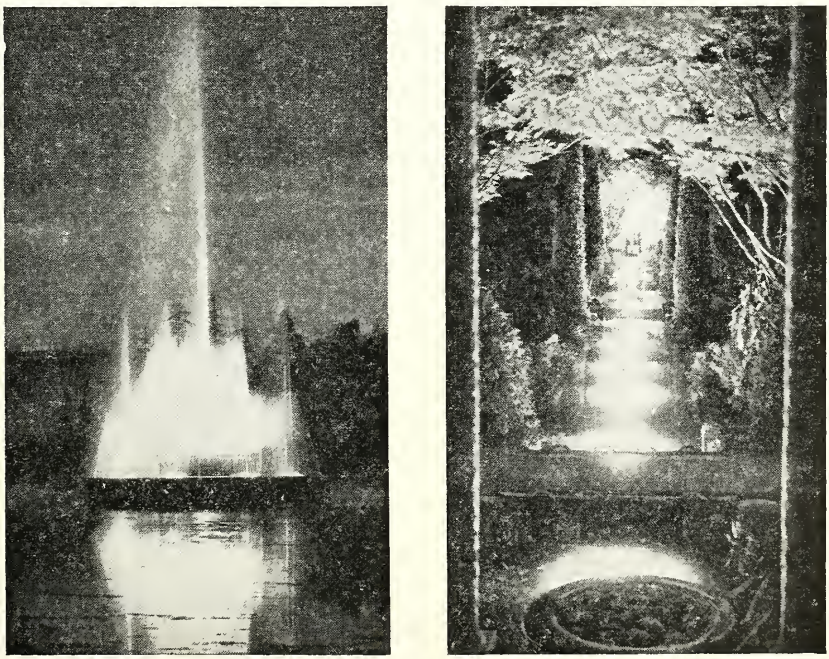


FIG. 11-20. Night-time appearance of lighted fountains and pools.

PROTECTIVE LIGHTING

Protective lighting is used by industry as an aid in the prevention of accident, theft, and sabotage. In many instances, it may reduce fire risk and provide useful illumination for outdoor work at night. The most effective aid to persons intending malicious property damage is darkness, and it is the object of protective lighting to eliminate this ally of the intruder. An American War Standard, *Protective Lighting for Industrial Properties* (A-85-1942),* discusses the subject rather completely.

There are two basic systems of protective lighting which may be used. Frequently, the most practical and effective solution involves a combination of both.

The first method is to light the boundary approaches or fence lines. This method should be used only where the property is served by a substantial guard corps. The second method involves the lighting of large areas and applies particularly to those cases where buildings account for a relatively small part of the total property area. In such cases, boundary areas and fences, areas between buildings, vulnerable locations, and general yard areas should be illuminated. (See Fig. 11-21.)

Searchlights operated by guards are useful for protection and they should be employed with either system. They permit illumination of areas under suspicion and can supplement existing lighting at any given point at times of emergency.

Protective lighting, to be effective, should:

1. *Discourage or deter attempts at entry by intruders.* This may be accomplished by providing illumination in such a manner that a potential intruder will believe detection inevitable. Although lighting is an effective tool it should not be used alone. It should be employed with other measures such as fixed or patrolling guards, fences, alarms, etc. Glare alone should not be relied upon to keep the intruder away. He may be able to shield his eyes enough to effect an entrance.

2. *Make detection certain should entry be effected.* Protective lighting measures should not be confined merely to border areas unless a substantial guard is maintained.

3. *Avoid glare in the eyes of the guard.* In every possible manner, use light to aid the vision of the guard and hinder the vision of the intruder.

4. *Provide complete reliability.* Wiring and controls should be arranged for complete reliability. The lighting layout should be designed so that failure of a single lamp will not leave a dark spot vulnerable to entry.

5. *Provide adequate illumination.* The amount of light required depends upon the accessibility and vulnerability of the property. Table 11-13 includes recommended levels for various locations.

* Obtainable from the American Standards Association, New York.

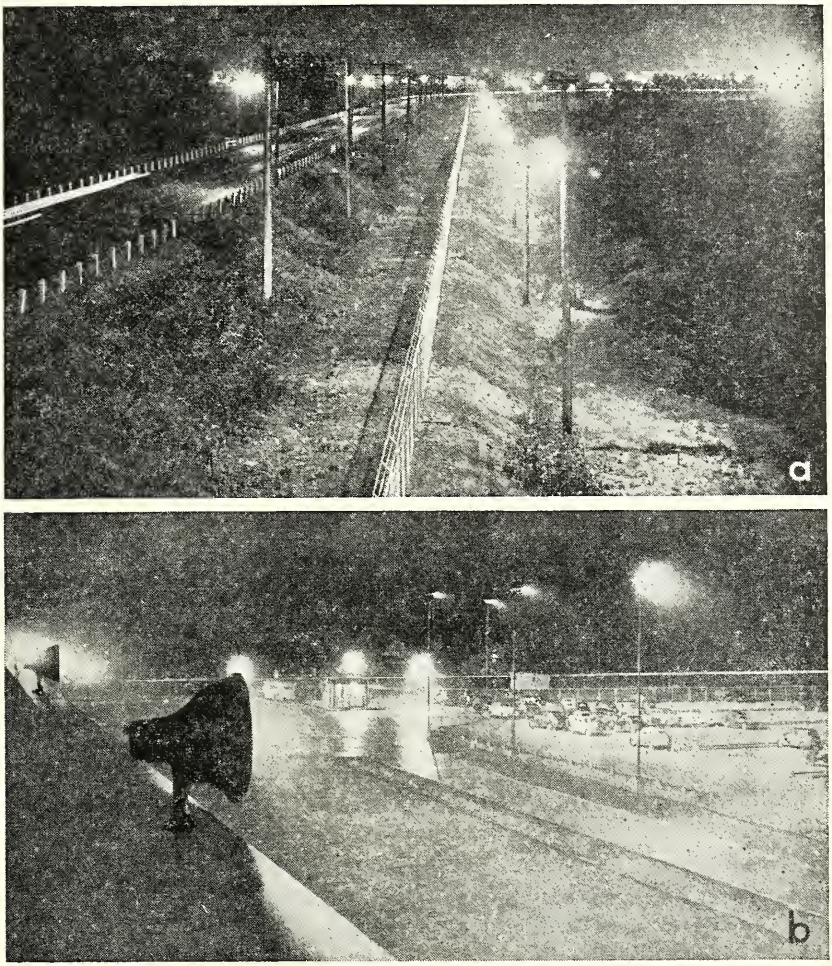


FIG. 11-21. a. Protective lighting for boundary approaches or fence lines. b. Protective lighting for large areas not occupied by many buildings.

Table 11-13. Recommended Illumination Levels for Protective Lighting

LOCATION	FOOTCANDLES ON HORIZONTAL
Fence lighting	0.15 to 0.20
Entrances, authorized	1.00 to 2.00
Entrances, unauthorized	0.15 to 0.20
Vulnerable locations	0.20
Water fronts	0.20
General area lighting	0.1 to 1.0
Shipping platforms	2.0
Walk paths	0.15
Internal roads	*

* Same as for street lighting (page 13-34).

Protective Lighting Equipment

Equipment used for protective lighting may be classified as follows:

1. Floodlights (including projector lamps).
2. Pendent luminaires.

In the latter group, there are two basic types, porcelain-enameled diffusers and lens-control luminaires.

Floodlights. Typical protective floodlighting applications are:

a. Long throws in yards. Boundary fences. Highlighting locations up to 1,000 feet.	Narrow beam	Floodlights
Lighting large areas within 400 feet. Lighting driveways from the side. Boundary fences.	Medium and Wide beams	Floodlights
b. Small yards, lighting behind obstructions, for emergency, lighting from building eaves.	Projector lamps	
c. Controlled by guard as auxiliary equipment for emergency use.	Searchlights	

Pendent luminaires. Pendent luminaires used for protective lighting include those with the candlepower distribution curves indicated in Fig. 11-22.

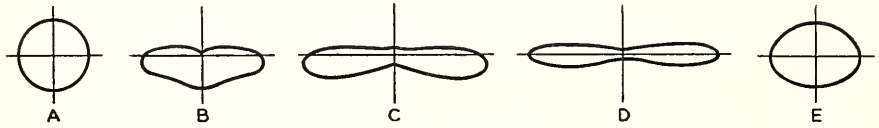


FIG. 11-22. Candlepower distribution curves for typical protective lighting luminaires. (Distribution in horizontal plane through light center.)

Distribution *A* is suitable for lighting general areas and intersections, and in some cases fence lines.

Distribution *B* is applicable to fence and boundary lines where a relatively wide light barrier is desired and comparatively close spacing of luminaires is possible. This type is suitable also for lighting areas between buildings that are not over 150 feet apart.

Distribution *C* is suitable for fence-line lighting and for lighting areas between buildings that are relatively close together. It also is applicable to the side of a building that forms the boundary line.

Distribution *D* is suitable for fence-line lighting and will provide relatively uniform illumination with comparatively great spacing of luminaires.

Distribution *E* is one-half distribution *A*. Units with this distribution are adapted particularly for mounting on the side of a structure to illuminate areas of greater width than could be covered with distribution B or C.

Lighting of Boundaries and Approaches

The lighting of boundaries and approaches to a property should be given first consideration. Five conventional methods of lighting such areas are summarized in Table 11-14. Both floodlights and pendent luminaires are employed.

Table 11-14. Conventional Protective Lighting Methods for Boundaries and Approaches

METHOD	LUMINAIRE	CANDLEPOWER DISTRIBUTION	LOCATION	MTG. HEIGHT (feet)	RECOMMENDED SPACING (feet)	LAMP RATING* (watts)	HORIZONTAL FOOTCANDLES
1	Floodlight	Narrow beam with horizontal spread lens	70–100 ft inside fence	20–25	170–200	500 1000	— —
2	Floodlight	Narrow beam or medium beam	5–12 ft inside fence	25–30	300 400	500 1000	0 2 0.33
3	Pendent refractor	†	15–20 ft inside fence	16–20	125	300 500	0.3 0.51
4	Pendent refractor	†	8–10 ft inside fence	25	125	300 500	0.18 0.31
			On side of bldg. that forms boundary	22–28	100 150	300 500	0.23–0.19 0.27–0.23
5	Pendent refractor	†	Directly over fence or 10 ft inside fence	25	125	300 500	0.20 0.34

* On a series circuit a 6,000-lumen lamp is equivalent to a 300-watt filament lamp on a multiple circuit, and a 10,000-lumen lamp is equivalent to a 500-watt filament lamp.
† See Fig. 11-22.

Lighting of Authorized Entrances

Either floodlights or pendent refractors should be used at entrances to provide from 1 to 2 footcandles illumination. (See Fig. 11-23.) Usually



FIG. 11-23. Floodlighting should provide 1 to 2 footcandles at authorized entrances.

wide-beam floodlights, mounted 25 feet or more above the ground on poles or convenient buildings, will be satisfactory. At least two floodlights should be used, to avoid darkness in case of a lamp burn-out in one. Symmetrical distribution pendent refractors may be used also, and should be mounted 22 to 25 feet high. At least two should be employed.

Lighting of Water Fronts

Water-front boundaries are a favorite approach for intruders. Method 1 for lighting boundaries (Table 11-14) may be applied if floodlights are so located that no shadow will be cast over the water by a sea wall, levee, or bank. Floodlights should be mounted at least 30 feet high and directed almost perpendicularly to the direction of the water traffic. A band of water paralleling the shore at least 100 feet wide should be illuminated, with no glare created for normal navigation. An average level of 0.2 footcandle (on the horizontal) usually is adequate.

Lighting for Emergencies

Emergency lighting falls into two classifications. The first of these requires a high candlepower which can be directed to cover a small area at any desired point. To accomplish this, it is recommended that searchlights be placed at convenient locations from which critical areas may be reached by their beams.

The second classification of emergency lighting includes conditions arising from fires, explosions, accidents, or the gathering of unruly crowds. To meet such contingencies, portable wide- and narrow-beam floodlights with adequate extension cords and, if necessary, portable power supplies should be available.

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SECTION 12

SPORTS LIGHTING

Though difficult visual tasks, such as following a fast-moving black hockey puck, a small white golf ball, or the sharp point of a fencer's foil, are encountered in sports, the necessity for concentration is not likely to be of long duration, and far, rather than near, vision is used mcs tfrequently. The exact nature of the seeing tasks, which varies over a wide range from sport to sport, has been standardized to some degree within each sport by the development of playing rules by local and national athletic organizations. These groups frequently specify the required characteristics and dimensions of equipment and playing areas.

The existence of such playing area standards has made it feasible to develop standard lighting plans for many types of playing areas, even though exhaustive research has not been devoted to the basic problems encountered. The best known sports lighting standards are those of the National Electrical Manufacturer's Association which are being studied by the I.E.S. Sports Lighting Committee.

On the basis of practical experience with installations throughout the United States, the N.E.M.A. Standards have been improved from time to time, and by investigation of the fundamental problems it is expected that means for additional improvement may be developed.

Seeing Problems in Sports

The following factors, which influence light and vision relationships in all lighting application fields, are recognized as variable in sports lighting, whereas in other fields they often are assumed to be constant:

Object of regard	Size (minutes)
	Location
	Path
	Velocity
Background	Average brightness
	Brightness pattern
Observer	Location
	Path
	Velocity

The objective of a sports lighting installation is to control the brightness of the object and the background to the extent that the object will be visible, regardless of its size, location, path, and velocity, for any observer location, path and velocity. In a majority of sports this objective is achieved by illumination of vertical rather than horizontal surfaces.

Objects to be seen. Dimensions and reflectances of typical objects that require the visual concentration of player, official, and spectator are listed in Table 12-1 with the usual range of distances over which each must be observed.

NOTE: References are listed at the end of each section.

Table 12-1. Approximate Dimensions, Reflectances, and Viewing Distances for Various Objects Used in Sports

SPORT	OBJECT	DIMENSIONS (inches)	APPROXIMATE REFLECTANCE* (per cent)	RANGE OF VIEWING DISTANCES (feet)	
				Player	Spectator
Badminton	Bird	Feathers $2\frac{1}{2}$ long cemented to $\frac{3}{4}$ half sphere	80	1–65	20–100
Baseball	Ball	9 to $9\frac{1}{2}$ (circumference)	75	1–400	25–700
Softball	Ball	12 (circumference)	75	1–250	20–350
Basketball	Ball	30 to 32 (circumference)	30	1–90	10–150
Bowling	Ball	27 (circumference)	10	1–85	10–115
Foot racing	Man	69 ± 7 (high)	Depends on costume	5–330	30–400
Football	Ball	$21\frac{1}{4}$ to $21\frac{1}{2}$ (short circumference) 28 to $28\frac{1}{2}$ (long circumference)	30	1–300	0–450
Golf	Ball	Not less than 1.68 (diameter)	80	5–900	20–920
Hockey	Puck	3 (diameter) 1 (thick)	1	5–200	10–300
Table tennis	Ball	$4\frac{1}{2}$ to $4\frac{3}{4}$ (circumference)	80	1–35	10–70
Tennis	Ball	$2\frac{1}{2}$ to $2\frac{5}{8}$ (diameter)	75	1–120	10–120

*Values given are for clean new equipment. Multiply by $\frac{2}{3}$ to get average value for equipment in use.

In many games, a large portion of the playing skill developed by practice is the ability to estimate accurately object location, path, and velocity, which vary from play to play. The apparent location, path, and velocity of an object are influenced by the object-background brightness relationship and by the angle subtended by the object at the observer's eye. These factors are affected in turn by the uniformity of illumination over the object surface, by the uniformity of illumination throughout the object path, by the object surface reflectance, by the background brightness pattern, and by the observer's locations.

Background brightness. In many sports the normal background against which an object must be viewed by a player comprises all surfaces or space above, below, and on all sides of the player's position. Because a ball or other object may move rapidly through the field of view, the background brightness, if it is not uniform, may vary rapidly. For example, outdoors in daylight a baseball may be viewed against the relatively dark shaded grandstand area at one instant and in the next be silhouetted against the sky or sun. A football may be viewed against dark green grass, white snow, clear sky, a mottled pattern of spectators, or a player's jersey.

With electrical illumination from a few high candlepower sources concentrated on an outdoor playing field and filling the space above to a limited altitude only, most of the background area is relatively dark and great care must be taken to be sure that in addition to providing relatively uniform illumination the sources are so placed that the number of times a ball must be viewed against them during games is small.

Indoors, as, for example, in a squash court with white walls, ceiling, and floor, and with indirect illumination, the background brightness is much more uniform.

Observer location. In designing lighting for sports, careful consideration should be given to the requirements and comfort of each of three observer groups: players, officials, and spectators, whose orientation with respect to the object differs. The normal fields of view of each group differ also and in the case of player and official there may be no fixed location. The probable variation in location and field of view will be different for each sport.

In providing adequate illumination of proper quality for one group, if possible no glare should be introduced into the field of view of the other two.

Quality and Quantity of Illumination

Diffuse illumination, such as that provided by an overcast sky on an outdoor playing field during the day or that provided by an indirect electric lighting system in an interior with high reflectance ceilings, walls, and floors, is considered to be of excellent quality for sports. Indoors the design problems are quite similar to these encountered in other interior occupancy areas. Outdoors the problem is more difficult, and it has been necessary to develop practical minimum diffusion standards which will provide satisfactory results. See Fig. 12-1c.

Number and location of sources. The shape and surface characteristics of the object to be seen and its probable orientation with respect to the observer are important factors in establishing minimum diffusion standards. Fortunately, balls with diffuse surface reflectance are the most common objects to be viewed. A point light source located in such a position that its central axis forms an angle of not more than 30 degrees with the observer's line of sight (apex at the ball) will for practical purposes illuminate the entire ball surface facing the observer. (See Fig. 12-1*a*.)

If the angle is increased to 90 degrees, the ball will remain lighted over half its visible surface, as shown in Fig. 12-1*b*. Figure 12 1*c* shows the same tennis ball lighted from above by two point sources that form angles of 85 degrees

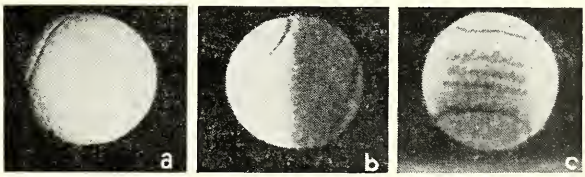


FIG. 12-1. Appearance of tennis ball lighted in different ways: a. by single source 30 degrees to right of line of sight; b. by single source 90 degrees to left of line of sight; c. by light from two sources above and at 85 degrees from line of sight, and by light reflected by the ground.

with the line of sight and from the ground by reflected light. It appears that the arrangement shown in Fig. 12-1c will provide illumination satisfactory for more observer locations than will the others. However, in the practical case the specific source locations selected will be those which offer the best compromise between desired illumination diffusion and minimum glare in the majority of observer locations.

It is necessary that illumination at points throughout the entire space above the playing area through which a ball may travel be fairly uniform (with no sharp changes in level), since a fast-moving object passing quickly from a light to a dark space will appear to accelerate. This occurs when there is inadequate overlap in floodlight beams. Such a condition distorts the player's judgment of ball trajectory.

Illumination level. In establishing the recommended illumination levels practical variables, which are considered in relation to the basic questions of object size and brightness and time available for seeing, include the following:

Speed of play (novice, expert, semiprofessional, professional).

Distance to spectators.

Orientation of spectators.

The values given in Table 12-2 have been found satisfactory when the proper quality of illumination is provided at the playing level and also (in some sports) in the space above.

Daylighting for Sports

Daylight usually provides adequate illumination to permit satisfactory participation in morning and afternoon outdoor contests even on cloudy and overcast days.

The daylighting principles set forth in Section 9 should be applied in the design of gymnasiums and other interiors used for indoor daytime athletics. To prevent skylight and window breakage glass should be screened. Since screening may have a very low transmittance, the utilization factor for screened windows will be low (15 to 60 per cent depending on screen transmittance characteristics).

Electric Illumination for Indoor Sports

The walls and ceilings of interiors used for sports provide a means for controlling background brightnesses, assist in diffusing the available light, and make possible a variety of convenient lighting equipment arrangements. The design and calculation procedures outlined in Section 8 are applicable to interiors used for sports. However, in addition to luminaire mounting height, spacing, and lumen output, and illumination uniformity on a horizontal reference plane, which are important factors in most installation plans, it is necessary in designing sports lighting to consider also the following factors:

1. Observers have no fixed visual axis or field of view and may be expected to look frequently at the ceiling and luminaires and in every other direction at some time during a game.
2. The object of regard will have no fixed location, being viewed from time to time on the floor, near the ceiling, or almost anywhere in between.
3. It is particularly important for observers to be able to estimate accurately object velocity and trajectory.

Table 12-2. Recommended Illumination Levels for Sports

	AVERAGE ILLUMINATION MAINTAINED IN SERVICE ON HORIZONTAL PLAYING SURFACE (footcandles)		SEE FIG.
ARCHERY (on target)			
Tournament		10	12-2
Recreational		5	
BADMINTON			
Tournament		30	12-3
Club		20	
Recreational		10	
	Infield	Outfield	
BASEBALL			
Major League	150	100	12-15
AA and AAA League	75	50	
A and B League	50	30	
C and D League	30	20	
Semipro and Municipal League	20	15	
On seats during game	—	2	
On seats before and after game	—	5	
BASKETBALL			
College and professional		50	12-9
High school		30	
Recreational		10	
BILLIARDS (on table)			
Tournament		50	12-5
Recreational		30	
General area (surrounding table)		10	
	General	On the pins	
BOWLING			
Tournament	20	50	12-6
Recreational	10	30	
BOWLING ON THE GREEN			
Tournament		10	
Recreational		5	
BOXING or WRESTLING (ring)			
Championship		500	12-7
Professional		200	
Amateur		100	
Seats during bout		2	
Seats before and after bout		5	

Table 12-2. Recommended Illumination Levels for Sports—Continued

	AVERAGE ILLUMINATION MAINTAINED IN SERVICE ON HORIZONTAL PLAYING SURFACE (footcandles)		SEE FIG.
CROQUET			
Tournament		10	
Recreational		5	
CURLING	Tees	Rink	
Tournament	20	10	
Recreational	10	5	
FOOTBALL			
Class Index: Distance* from nearest sideline to the farthest row of spectators			
I Over 100 feet		100	12-14
II 50 to 100 feet		50	
III 30 to 50 feet		30	
IV Under 30 feet		20	
V No fixed seating facilities		10	
GOLF DRIVING			
General on the tees		10	12-13
On vertical surface at 200 yards		3	
Practice putting green		10	
GYMNASIUMS			
Exhibitions and matches		30	12-9
General exercising		20	
Lockers and shower rooms		10	
HANDBALL			
Tournament		30	12-3
Club		20	
Recreational		10	
HOCKEY			
College or Professional		50	12-12
Amateur League		20	
Recreational		10	
HORSESHOES			
Tournament		10	
Recreational		5	
RACING			
Bicycle		20	
Motor (midget auto or motorcycle)		20	
Horse		20	
Dog		20	
	Outdoor	Indoor	
RIFLE RANGE			
On target	30	50	12-2
Firing line	10	10	
Range		5	

*It is conceded generally that distance between the spectators and the play is the first consideration in determining the class and lighting requirements. However, the potential seating capacity of the stands should also be considered and the following ratio is suggested: Class I for over 30,000 Spectators; Class II for 10,000 to 30,000; Class III for 5,000 to 10,000; and Class IV for under 5,000 spectators.

Table 12-2. Recommended Illumination Levels for Sports—Concluded

	AVERAGE ILLUMINATION MAINTAINED IN SERVICE ON HORIZONTAL PLAYING SURFACE (footcandles)		SEE FIG.
ROQUE			
Tournament		20	
Recreational		10	
SHUFFLE BOARD			
Tournament		10	
Recreational		5	
SKATING			
Rink		5	12-12
Park, lagoon, or pond		1	
SKEET SHOOT			
Target (vertical surface at 100 feet)		30	12-2
Firing point (general)		10	
SKI PRACTICE SLOPE		.5	
SOCCER			
Professional and college		30	12-14
High school		20	
Athletic field		10	
	Infield	Outfield	
SOFTBALL			
Professional and championship	50	30	12-16
Semipro	30	20	
Industrial league	20	10	
Recreational	10	5	
SQUASH			
Tournament		30	12-3
Club		20	
Recreational		10	
SWIMMING POOLS			
General		10	12-8
Underwater	5 watts per square foot of pool surface		
	Lawn	Table	
TENNIS			
Tournament	30	50	12-4
Club	20	30	
Recreational	10	20	
TRAP SHOOTING			
Target (vertical surface at 150 feet)		30	12-2
Firing point (general)		10	
VOLLEY BALL			
Tournament		20	12-9
Recreational		10	

Design Recommendations

Factors 1 and 2 page 12-5 make it particularly desirable to provide large-area, low-brightness luminaires such as these utilizing fluorescent lamps. High wall, ceiling, and floor reflectances will be appropriate also, since they are likely to result in reduced brightness ratios in all possible fields of view. Considerable object-background contrast is necessary for good visibility.

Factor 3 calls for high-reflectance surfaces also, since interreflections contribute materially to light diffusion and therefore to illumination uniformity on and above the reference plane. Uniformity is necessary if object velocity and trajectory are to be estimated accurately.

If fluorescent lamp luminaires are recommended, it is essential that they be operated on lead-lag ballasts or on three-phase circuits so that the visibility of moving objects will not be reduced by stroboscopic effect.

Aerial sports. Archery, badminton, basketball, handball, squash, tennis, and volley ball are included in this classification. Such sports may require that observers look toward the ceiling during a large portion of the playing time. In planning general lighting installations for these sports every effort should be made to select, locate, and shield the light sources to avoid introducing glare into the observer's view. [1, 2, 3, 4] (See Figs. 12-2, -3, and -4.)

Low-level sports. Billiards, bowling, fencing, curling, shuffleboard, skating, swimming, boxing and wrestling, and other sports in which observers in the normal course of play do not look upward are called low level sports. General lighting may be planned more easily for these sports than for the aerial type, since luminaire brightness is less critical.[5, 6, 7] (See Figs. 12-5, 12-6, 12-7, and 12-8.)

Arenas and gymnasiums. In these areas uniformly distributed general illumination usually is provided over the entire playing floor so that basketball, volley ball, track and field events, gymnastics, fencing, calisthenics, hockey, or dancing may be accommodated.[8, 9, 10] (See Fig. 12-9.)

When high-caliber play in tennis, badminton, and other small court games is contemplated, supplementary illumination should be provided on the court.

Since arenas are likely to be public exhibition places, the principles of stage lighting presented in Section 10 may be applied to the boxing ring or playing floor.

Maintenance. If it is likely that lamp operating time will be of the order of 200 hours per year or less, a cost analysis should be made to determine the relative advantage of operating incandescent lamps at a voltage 10 per cent above their rating.

To prevent breakage it may be necessary to cover otherwise unprotected luminaires with wire mesh. This will reduce their efficiency and should be compensated for in the design by multiplying the luminaire efficiency by the average transmittance of the mesh.

Good practice. Table 12-2 lists recommended illumination levels for a number of sports and refers to line and photographic illustrations showing sports lighting installations.

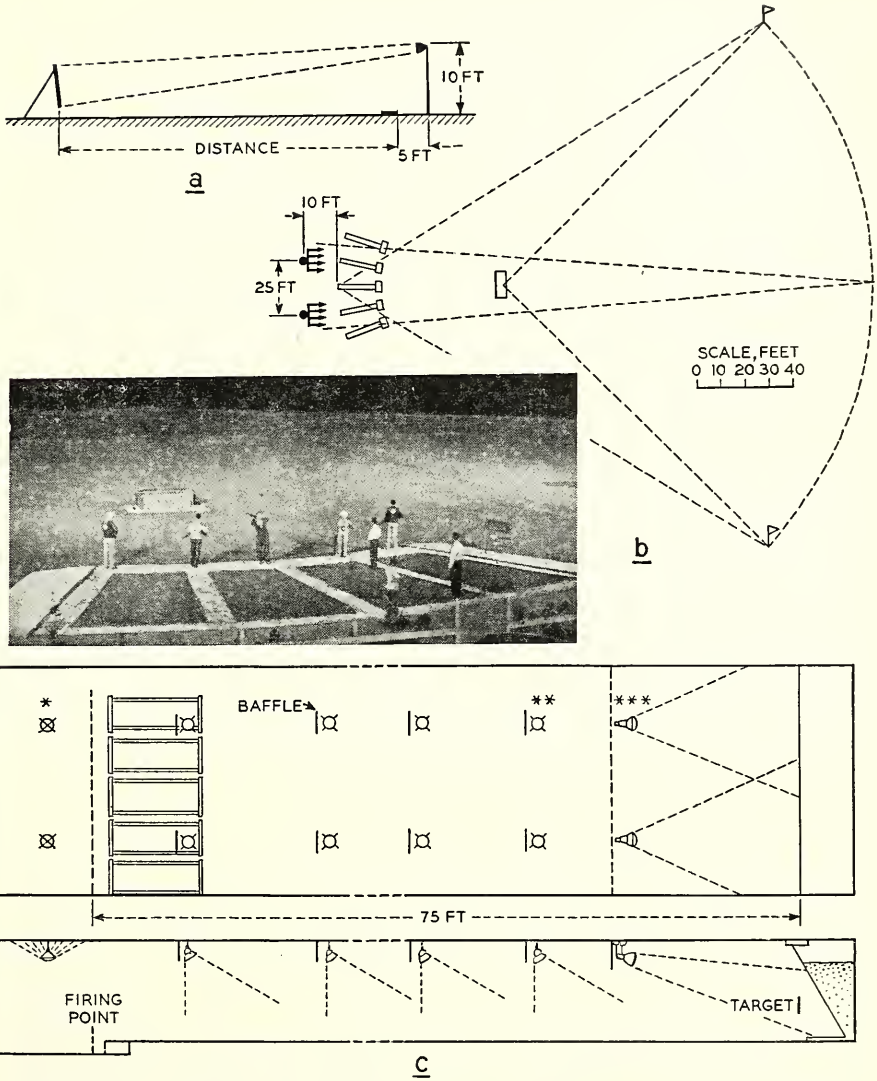


FIG. 12-2. Lighting for various types of shooting: a. Archery, one 10- to 18-degree beam spread floodlight required per target.

LAMP	DISTANCE
250-watt, G-30 bulb	Up to 30 yards
500-watt, G-40 bulb	30 to 50 yards
1,000-watt, G-40 bulb	50 to 100 yards

b. Skeet, eight 18- to 35-degree beam spread floodlights with 1,000-watt clear PS-52 bulb lamps are mounted 20 feet above the ground. c. Rifle, *300-watt general service lamp in an indirect luminaire. ** 200- or 300-watt clear bulb general service lamps behind beams or baffles or in angle reflectors. *** For each group of five targets, two floodlights with horizontal spread lenses and 750- or 1,000-watt clear bulb general service lamps.

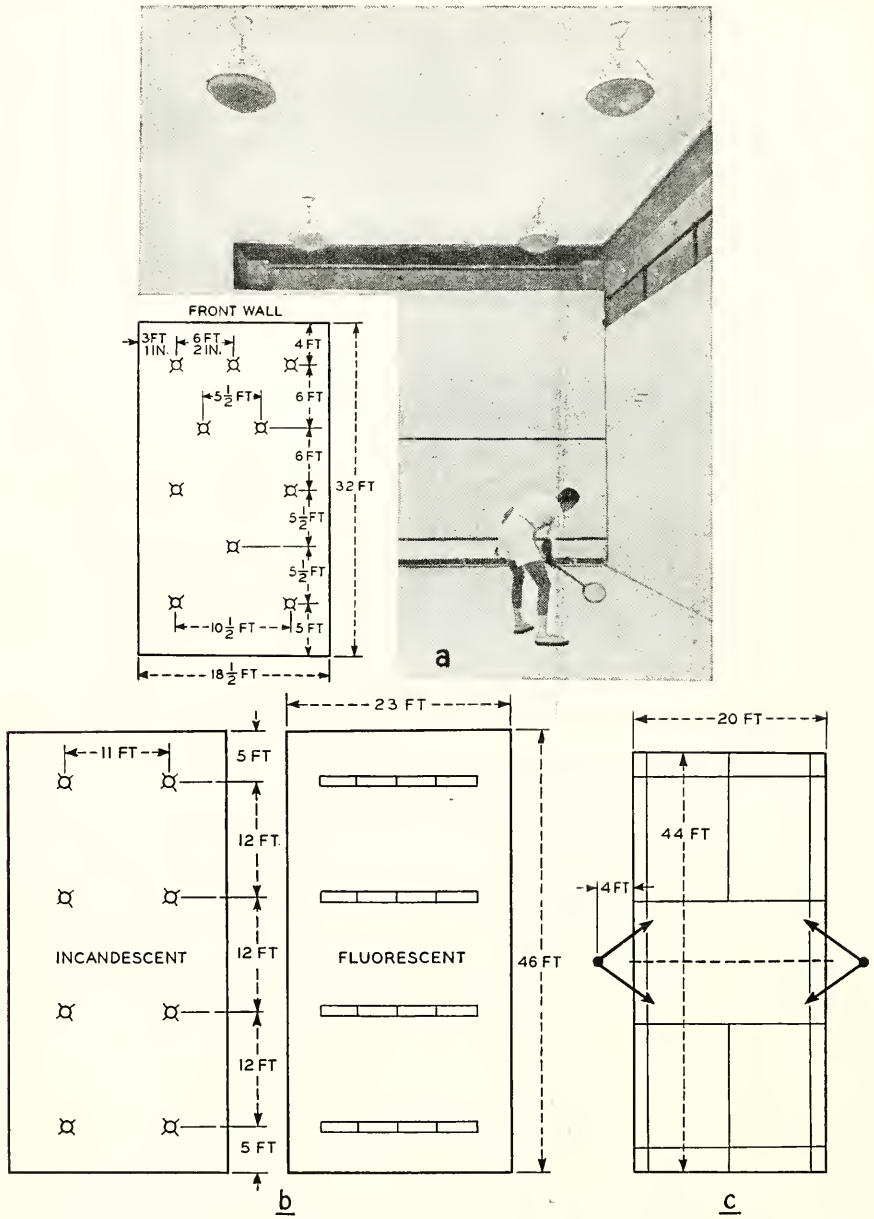
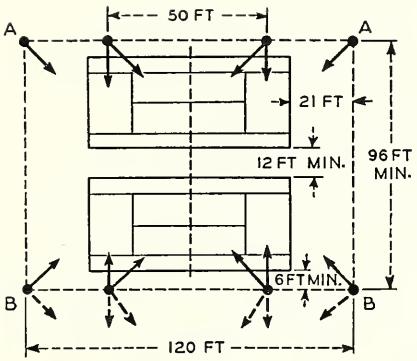


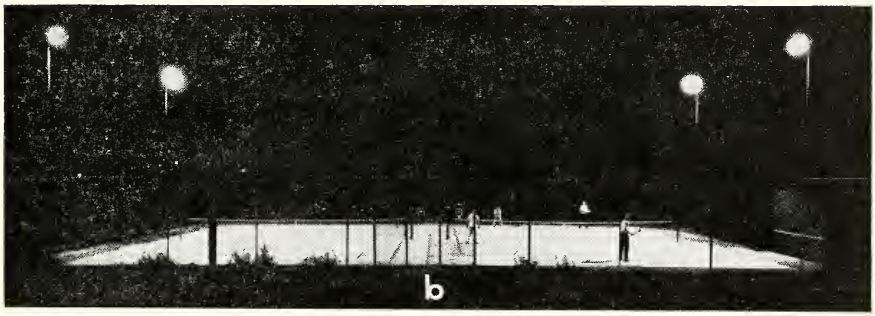
FIG. 12-3. Lighting for small court games: a. Squash, ten ceiling-mounted Glassteel diffuser type luminaires with wire guards or four 1,000-watt indirect reflectors with netting protection may be used as shown in plan and photograph respectively. b. Handball, eight 750-watt Glassteel diffuser type luminaires or sixteen three-lamp 40-watt direct flourescent type luminaires may be recessed or ceiling mounted behind wire guards. c. Badminton, outdoors four 70° beam spread floodlights per court mounted 20 feet above ground may be used with 500-watt clear PS-40 bulb general service lamps.



Double Courts
Mount twelve 70° beam spread 1,500-watt floodlights 30 feet above ground

Single Courts
Move poles on line BB to line adjacent to court. Use 1,000-watt lamps.

a



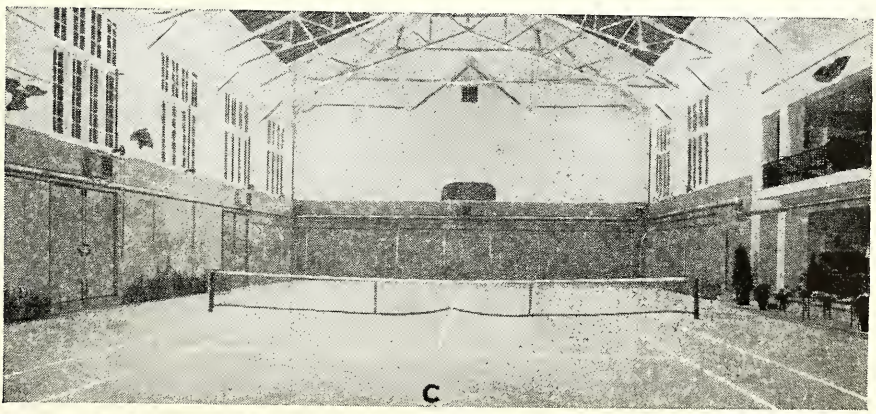
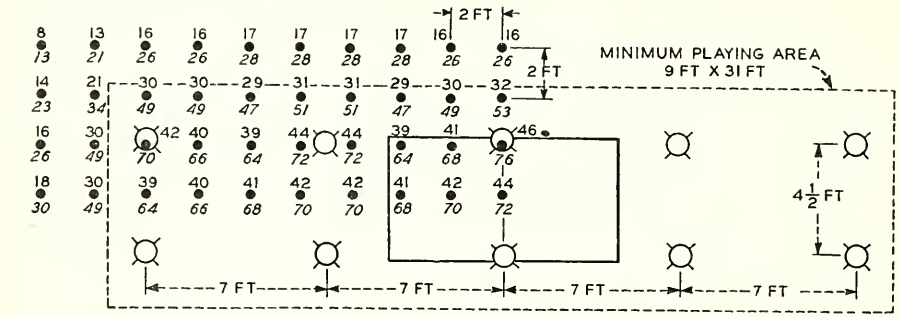
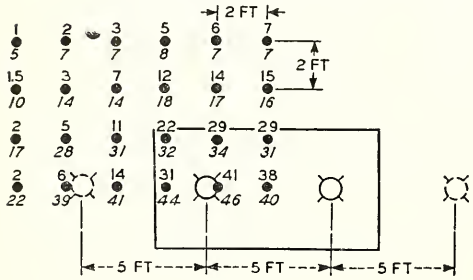


FIG. 12-4. Lighting for tennis courts: a. layout for tournament play; b. playground installation of eight 1,000-watt floodlights. Two floodlights are mounted on each of the four poles 30 feet above the courts. c. indoor court installation of one hundred forty 200-watt lamps in angle reflectors. Reflectors are mounted at wall-ceiling intersection. Roof and sidewall windows provide daylight for daytime play.





a

Table Tennis

Club Plan (above)

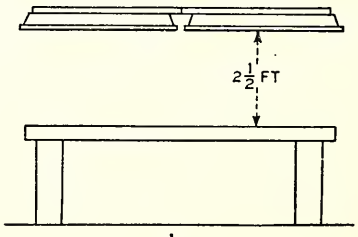
Luminaires	10 deep cone or bowl shades
Location	6 ft above table
Illumination by 10 inside-frosted filament lamps (footcandles)	(upper figures for club play) 150-watt lamps operated 5 volts above rating
	(lower figures for tournament play) 200-watt lamps operated 10 volts above rating

Home Plan

Luminaires	2 or 4 deep cone or bowl shades
Location	4½ ft above table
Illumination by 150-watt inside - frosted filament lamps (footcandles)	(upper figures for recreational play) 2 lamps
	(lower figures for skilled play) 4 lamps

Billiard Table

Lamp	*Fluorescent*	*Incandescent*
Luminaire	Direct (louvered)	Direct (louvered)
No. of Luminaires	2	2
Location	Over table center line	Over table center line
Mtg. hgt. (above table)	2 ft 6 in.	2 ft 6 in.
No. and rating of lamps	Four 40-watt	Two 200-watt



b

FIG. 12-5. a. Typical lighting layouts for championship table tennis and a home ping pong table. b. Typical lighting layout for a billiard table.

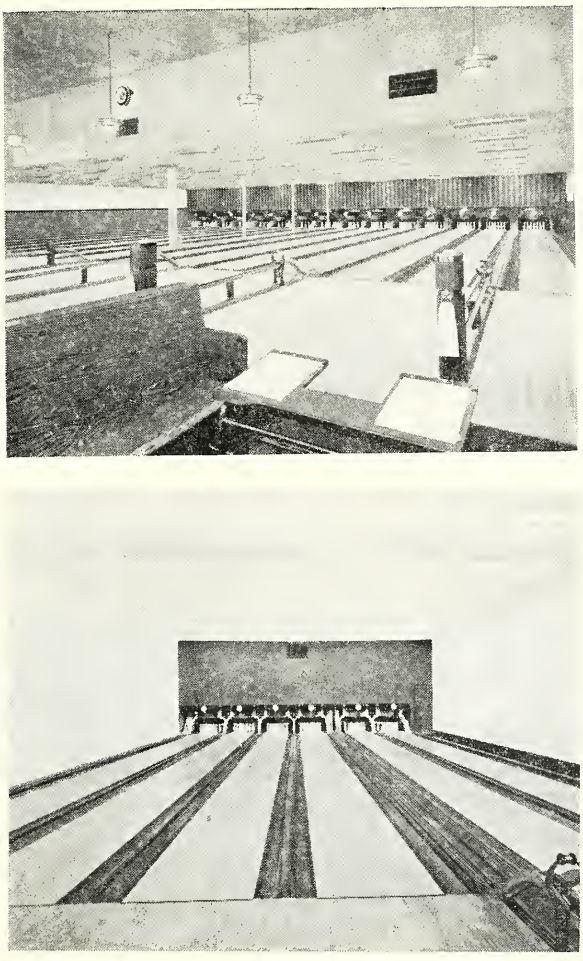


FIG. 12-6. Typical bowling alley lighting installations.

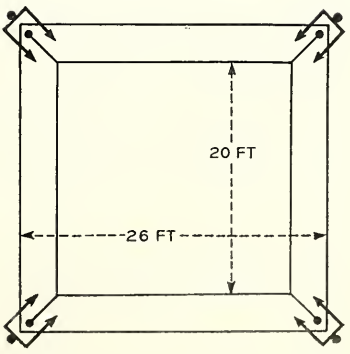
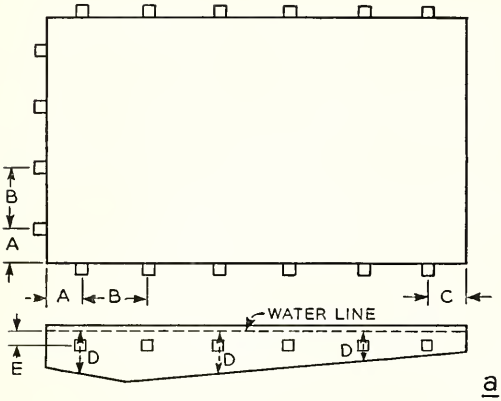


FIG. 12-7. Lighting layout for a boxing and wrestling ring. Floodlights with 40- to 70-degree beam spread for 1,500 watt lamps are mounted 15 to 18 feet above the ring. Number required: Class A—20; Class B—12; Class C—8.



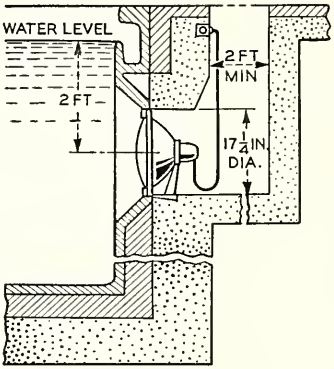
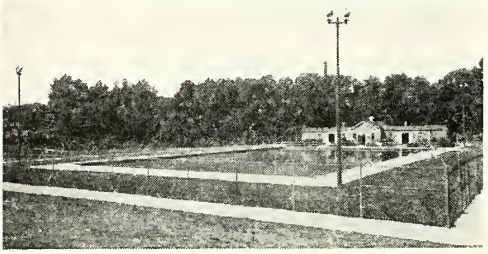


FIG. 12-8. a. Underwater floodlighting plan for swimming pools.

LAMP RATING* (watts)	EQUIPMENT SPACING					
	A (ft)	B_{max} (feet)		C (ft)	E (inches)	
		D>5 ft	D<5 ft		Min	Max
250 400	4	8	10	5	12	15
500 1,000 1,500	6	12	15	7½	18	24

* 3 Watts per square foot outdoors.
5 Watts per square foot indoors.



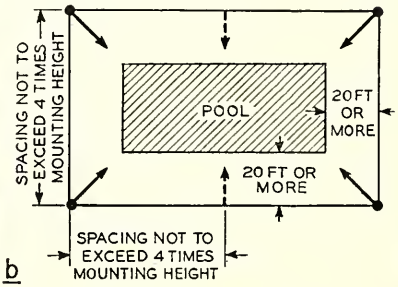


Fig. 12-8b. Overhead floodlighting plan for outdoor swimming pools. Floodlights are mounted 18–30 feet above the pool. Lamps should be selected to allow about 1.25 watts per square foot of lighted area.

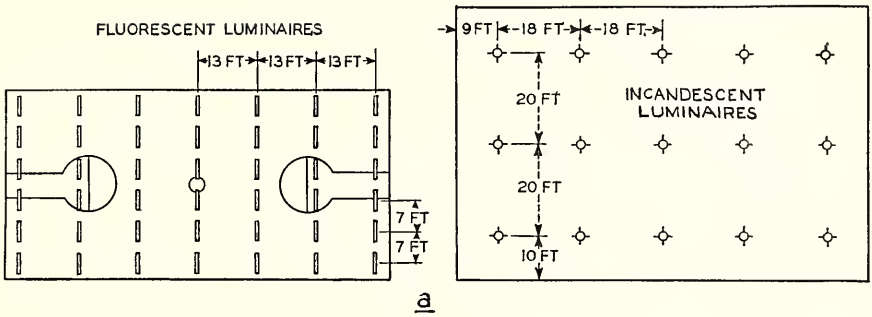


FIG. 12-9. a. Typical layouts for fluorescent and incandescent lamp luminaires in a school gymnasium. Forty-two fluorescent lamp luminaires (two 100-watt lamps each) or 15 incandescent lamp luminaires (one 1,000-watt lamp each) are mounted 20 to 30 feet above the floor.

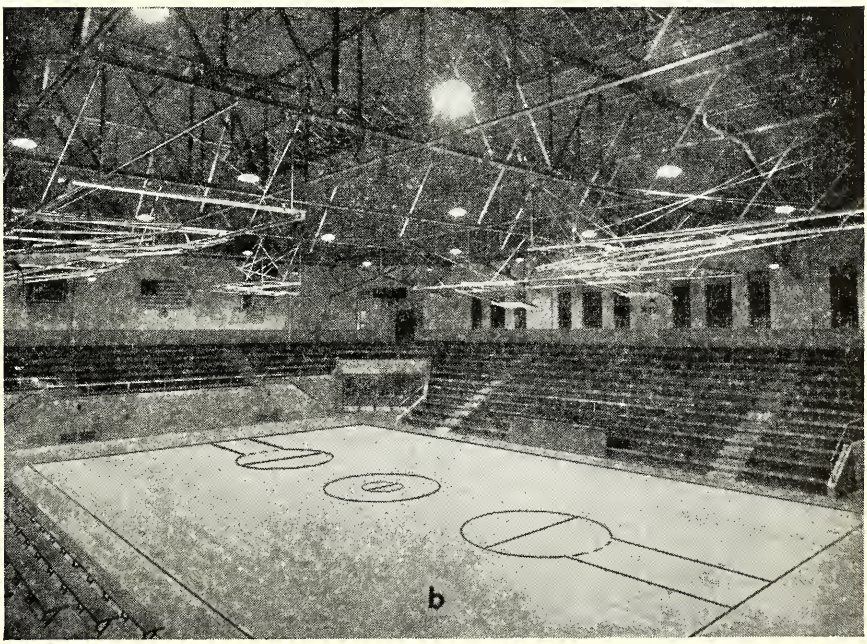


FIG. 12-9b. School gymnasium lighted by industrial type, high-bay incandescent lamp luminaires.

Electrical Illumination for Outdoor Sports

Most large outdoor sports areas may be regarded, for lighting design purposes, as large rooms with black walls and ceilings. Direct lighting provided by floodlights installed about the playing area usually is recommended because overhead suspension of luminaires with symmetric distribution often is not feasible.

Following the floodlighting design procedures in Section 8 (page 8-25) will result in satisfactory illumination uniformity on a playing area, but the first of the following three factors which are of particular importance in sports lighting may require that illumination uniformity in the space above the playing area be checked also.[11, 12, 13] This may be done with the point-by-point calculations procedure given also in Section 8. The important factors are:

1. Observers will have no fixed visual axis or field of view.
2. Object will have no fixed location or no fixed orientation with respect to the observer.
3. Observers should be able to estimate accurately object velocity and trajectory.

Under conditions 2 and 3, an object may be seen with ease and comfort by all observers only if light from several directions is incident upon it. Also, source brightness in the observers' fields should be reduced by careful floodlight location and aiming to minimize potential glare.

Floodlight selection. Floodlights are selected on the basis of photometric and mechanical considerations. The approximate photometric specifications will be established by the preliminary design calculations, by the examples of current practice in figures preceding and in those following, and by the balance between a small number of floodlights with high lumen output and a larger number with smaller output arrived at on the basis of desired results and economics.

Floodlights should be weather proof so that their operating characteristics will not be affected by sun, rain, snow, and so on. Lamps in open-type floodlights should be protected by reflectors or by hoods against rain, snow, or hail. All materials used should withstand weathering without objectionable corrosion. Enclosed (weather-tight) floodlights are preferable for most applications when specular reflectors are required.[14] (See Fig. 12-10.)

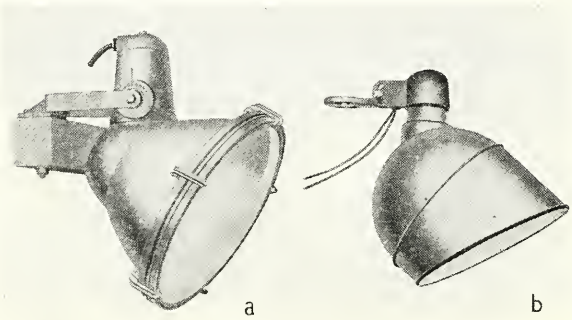


FIG. 12-10. Typical enclosed (a) and open (b) floodlights designed for sports field application. Lamps are operated in vertical base-up position.

When floodlight lamps are to be operated at voltages above their rating, as usually recommended when the annual hours of operation are to be of the order of 200 or less, it is desirable to select a floodlight in which the lamp will operate at or close to the base-up vertical position after aiming. Base-up burning reduces bulb-blackening and bulb-blistering failures. If it is planned to operate lamps at voltages above their rating in open floodlights, it sometimes is necessary to use hard-glass lamps to prevent breakage caused by wind-driven snow, rain, or hail.

When a detailed cost analysis is not feasible, the following general rules are recommended.

1. If the installation is utilized 200 or less hours per year, operate lamps 10 per cent above rated voltage.
2. If the installation is utilized over 200 hours per year but less than 1,000, operate lamps 5 per cent above rated voltage.
3. If the installation is operated for total periods approaching rated lamp life (generally 1,000 hours) in one year, operate lamps at rated voltage.

It is important to note that it is intended that the voltages indicated are to be available *at the lamp sockets* with the entire installation operating at the time of day, week, and month in which they will be utilized most.

Aiming of floodlights. In any design much depends on the aiming of the floodlights. In certain sports employing a symmetric field such as football, the development of an aiming or "spotting" pattern is relatively simple, requiring merely that scale drawings be made showing the field and the floodlight-beam-spread angles. From an end elevation view, the vertical aiming of the floodlight beam axes may be determined to obtain uniform lighting across the field together with sufficient "spill," "direct filament," or "beam-edge light" in the space above to provide uniformity to a height of 40 to 50 feet above the field. In this connection, care must be taken to minimize the amount of light from the upper portion of the floodlight beams falling in the opposite spectator stands. The plan view of the field makes it possible to plan horizontal aiming of the floodlights to provide uniform lighting in the longitudinal direction of the field. Rigorous calculation methods make it possible to predetermine accurately the footcandle distribution provided by any given aiming pattern, but because such calculations are tedious, it is general practice to base spotting or aiming diagrams on previous calculations and practical experience with similar fields.[15]

A typical football spotting diagram is shown in Fig. 12-11*a* while Fig. 12-11*b* shows an end elevation view of the vertical beam coverage of two typical floodlights aimed in accordance with the diagram. It will be noted in this case that relatively wide beam floodlights (60 degrees) are used because the poles are close to the playing field. It will be noted also that the upper parts of the beams of the two sets of floodlights indicated fall in the opposite stands. However, since these are the wide beam type, the candlepower in these upper portions (more than 16 degrees from beam center) will be low, and the spill brightness from them will be within comfortable limits when evaluated with respect to the relatively high brightness of the field itself.

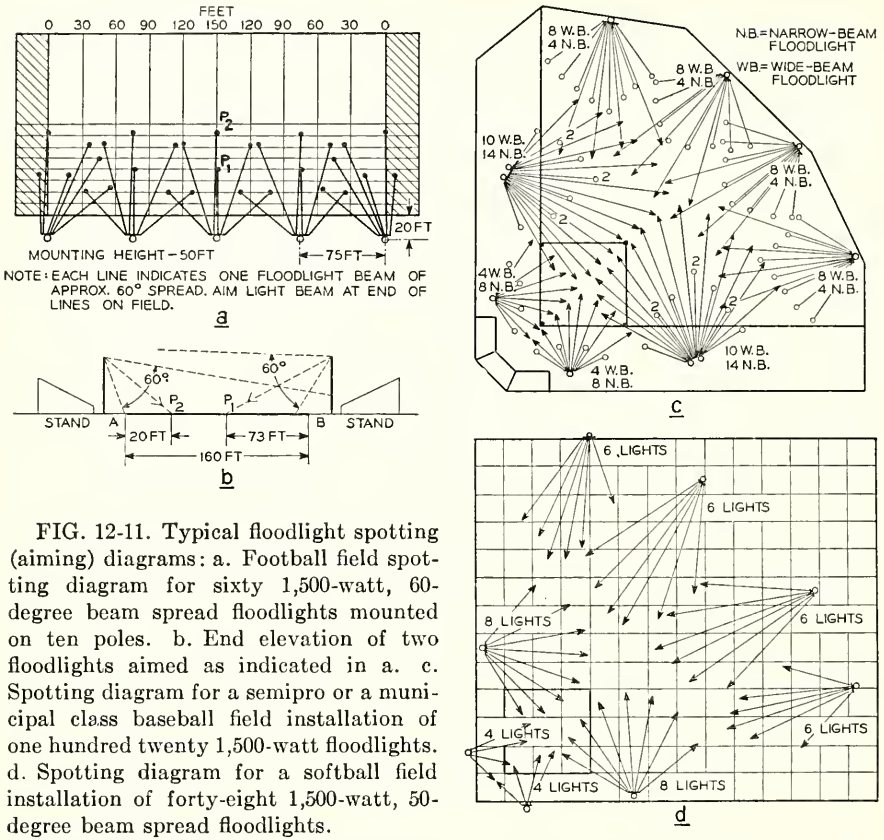


FIG. 12-11. Typical floodlight spotting (aiming) diagrams: a. Football field spotting diagram for sixty 1,500-watt, 60-degree beam spread floodlights mounted on ten poles. b. End elevation of two floodlights aimed as indicated in a. c. Spotting diagram for a semipro or a municipal class baseball field installation of one hundred twenty 1,500-watt floodlights. d. Spotting diagram for a softball field installation of forty-eight 1,500-watt, 50-degree beam spread floodlights.

Similar diagrams are in general use for other sports. (See Fig. 12-11*c* and Fig. 12-11*d*.)

There are several ways to put spotting or aiming information to use in making an installation. First and most accurate is manual aiming of the floodlight beam centers at predetermined spots on the playing area, as, for example, on Fig. 12-11*a*. This may be accomplished by using built-in beam sights or by placing accessory beam sights against floodlights parallel to their optical axes. Markers then are placed at the aiming points and the sights aimed at these points by an engineer at the light.

A second aiming method is to calculate or determine graphically from the aiming diagram the vertical and horizontal angular setting of each floodlight. Most floodlights are equipped with degree scales which may then be set to those angles. However, the accuracy of this method is limited, first by tolerance in the leveling and aligning of mounting pole cross-arms and second by the difficulty of setting the wide pointers accurately at the proper position on the cast scales, which generally have coarse graduations. A difference of several vertical degrees may move the beam center 20 feet or more on the field.

A third aiming method which may be used successfully with practice is to stand an observer on the field ahead of the aiming point (so the line from the floodlight to the aiming point passes approximately through the observer's eyes) and observe the floodlight, preferably through binoculars. As the floodlight is moved by an assistant, the observer then estimates the position in which the lamp filament (or concentric reflector rings) appear exactly centered in the floodlight aperture. An alternate observation method that may be used with the narrow-beam type (specular-reflector) floodlight is to light the lamp and, with smoked glasses on (preferably with binoculars), estimate when the entire reflector appears uniformly bright and at a maximum brightness. The latter methods are inherently less accurate than the first method but may be satisfactory when relatively large numbers of medium or wide beam floodlights are directed into the same general area.

Maintenance. The factors of overvoltage lamp operation and relatively few hours of operation per year should be considered in setting up a maintenance program for outdoor sports lighting installations. Overvoltage operation causes lamps to blacken earlier than rated voltage operation. Consequently, the lamps should be checked periodically for this dererioration and replaced when it becomes evident. The relatively small number of hours of operation per year may result in long intervals between lamp replacements. Therefore, reflectors, cover glasses, and lamps should be cleaned often enough (between relampings, if necessary) to maintain a schedule of at least two cleanings per year, or more if the locale is such as to cause rapid dirt accumulation.

Care should be taken to maintain voltage at the lamps at the selected level as any variation will have a considerable effect on light output and lamp life.

Good Practice

Table 12-2 lists recommended illumination levels for a number of sports and refers to line and photographic illustrations showing sports lighting installations in which the recommendations have been carried into practice. (See Figs. 12-12 and 12-13.)

In the following discussion, where various "classes" of sports are indicated, the classifications (A, B, C, Semiprofessional, and so on) follow "league" ratings where they exist. In general, these ratings are indicative of the skill and speed of play to be expected and correlate closely with the relative number of spectators regularly accommodated. This latter factor determines the maximum distance at which a spectator may be observing the playing area and consequently has a direct bearing on the angular size of the object to be seen and, therefore, on the quantity of light required.

Football. American football is a combination of aerial and ground play requiring uniform lighting from ground level to 40 or 50 feet above the ground. The problem of providing a good quality of lighting is not difficult except in special cases of awkward stand locations.[15,16,17,18,19,20,21,22,23,24,25] Figure 12-14 presents data for layouts considered good practice.

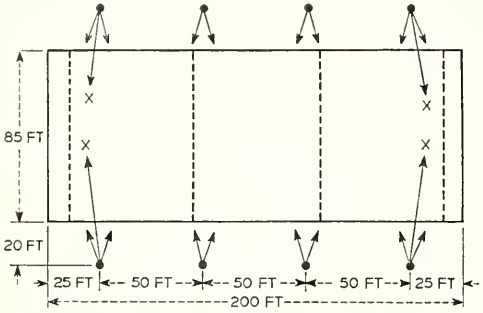
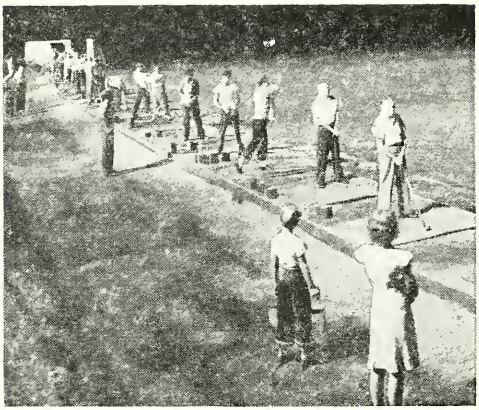


FIG. 12-12. Lighting layout for an ice hockey rink. The following floodlights are mounted 40 feet above the ice:

NO.	BEAM SPREAD	LAMP
16	<70°	1,500-watt
4*	25°–40°	1,000-watt

* To be aimed at points marked X.



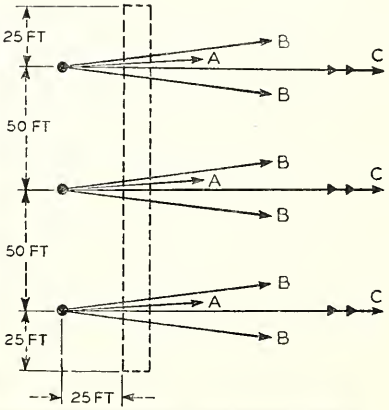
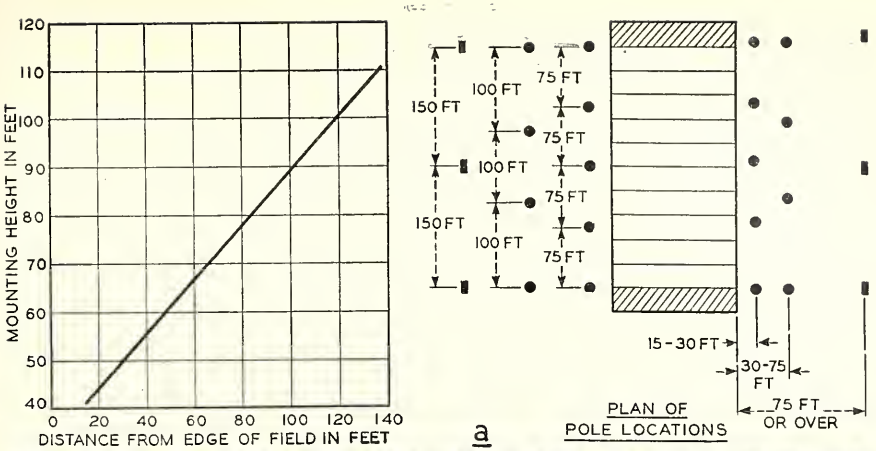




FIG. 12-13. Golf driving range lighting equipment layout and installation photographs. The letter symbols designate the following floodlights:

A—one 70° beam spread type
B—two 25° to 40° beam spread type } 1,500-watt lamp
C—three 10° to 25° beam spread type } 1,000-watt lamp

All are mounted approximately 30 feet above the ground.



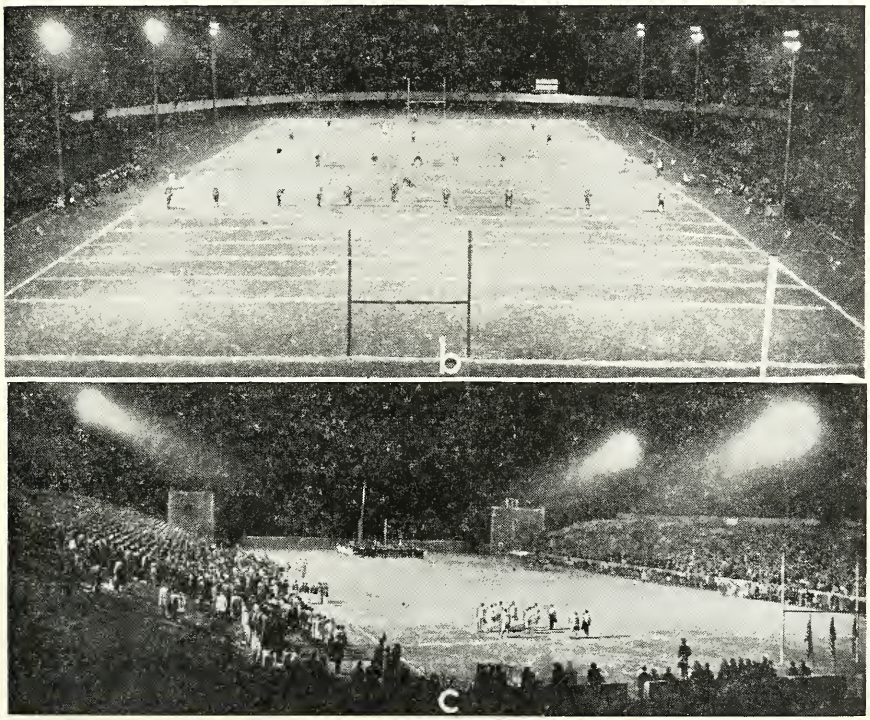


FIG. 12-14. Football field lighting: a. Standard layout of 1,500-watt floodlights.

DISTANCE FROM FIELD EDGE (feet)	NO. OF POLES	NO. FLOODLIGHTS PER POLE — Installation Class				DISTANCE FROM FIELD EDGE (feet)	FLOODLIGHT BEAM SPREAD
		A	B	C	Minimum		
<30	10	12	8	6	4	<30	>70°
30–75	8	16	12	9	6	30–60	40° to 70°
>75	6	24	18	14	9	60–90	25° to 40°
						>90	10° to 25°

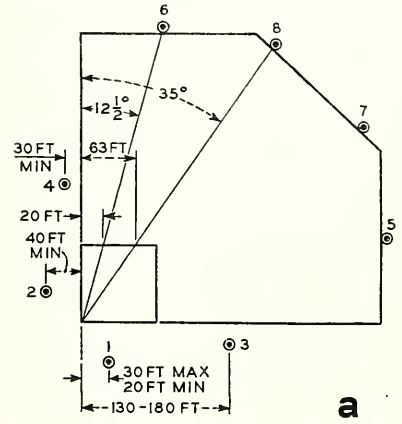
b. Class C football field lighting. c. Class A football field lighting.

The beam spreads indicated in Fig. 12-14*a* for the various pole locations are intended as a guide. Equally satisfactory results may be obtained in each of the indicated zones of pole locations by using combinations of narrow beam and wide beam reflectors provided they are properly selected and aimed.

A typical spotting or aiming diagram is presented in Fig. 12-11*a*, covering a Class C installation on ten poles erected 20 feet from the side lines.

Figure 12-14*c* shows a night view of a typical Class A football field lighted by approximately 140 floodlights.

Baseball. Baseball presents a severe though not prolonged seeing task. The ball is small, moves rapidly, and is viewed at varying distances against variable background brightnesses. The necessity for concentration is intermittent. The large number of possible observer locations and the probability that observer-players will be in motion introduce difficulties also.[15,16,17,19,20,23,24,26,27,28,29] Figure 12-15*a* presents data for layouts considered good practice.



INSTALLATION DATA

Class	*No. 1,500-watt Floodlights*	*Mtg. Ht. (feet)*
Major League	**750**	**150**
AAA and AA	**400**	**120**
A and B	**240**	**100**
C and D	**160**	**80**
Semipro and Municipal	**120**	**80**
Minimum	**100**	**60-80**

Location of Floodlights		
Pole No.	**1, 2, 5, 6, 7, 8,**	**3 and 4**
% total no. per pole	**10**	**20**

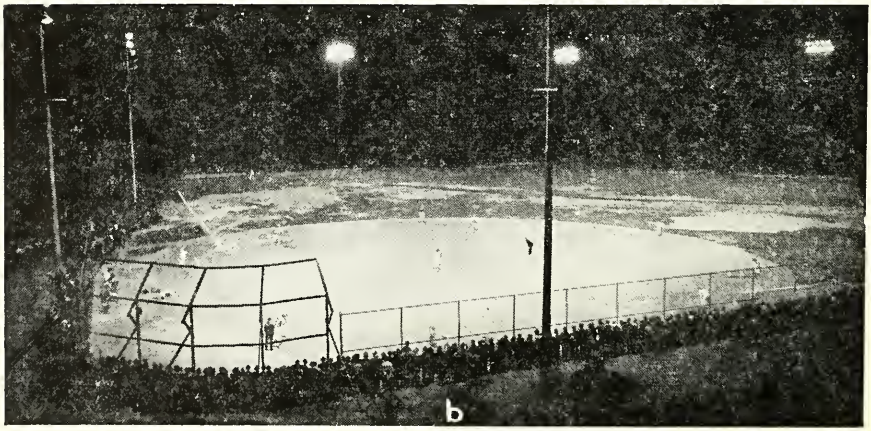


FIG. 12-15. a. Standard floodlighting layout for baseball fields. b. Minimum baseball field installation of 100 floodlights.

It will be noted that recommended floodlight beam spreads are not shown. These must be determined for each installation and will depend on number of floodlights installed, depth of the outfield, and location with respect to the infield of poles number 1, 2, 3, and 4. A typical spotting diagram for a Semiprofessional or Municipal, 120-floodlight installation such as shown in Fig. 12-11*c* will be of assistance in determining the general area covered from each pole, and thus in deciding on necessary beam spreads for the areas and distances to be covered. It can be seen that the floodlights are aimed so that beam overlap will provide lighting from two directions at almost every outfield point and from four directions over most of the infield.

In providing adequate and uniform illumination for baseball, it has become general practice to consider the infield as including a 30-foot strip outside all base lines and to consider the outfield as including a 30-foot strip outside both foul lines. (See Fig. 12-15*b*.)

Softball. In general, the baseball discussion will apply also to softball. The principal differences are that the ball is larger and the field smaller.[15, 16,17,18,19,21,23,24,30,31]

However, floodlights of less than 45 degrees beam spread seldom are used for softball installations. Normally, beam spreads of 70 degrees or more are used on poles carrying two lights; spreads of 45 to 70 degrees or more (or combinations of spreads) are used on three-light poles; and 45-degree spreads are used on poles carrying four or more floodlights. The majority of these installations are made with open-type floodlights, since usually these are less expensive.

In recent years softball has become so popular and its play so skilled in certain sections of the country, that some installations have been made with twice as many floodlights as indicated in Fig. 12-16. Such installations usually are made with the aim of approaching the baseball recommendations.

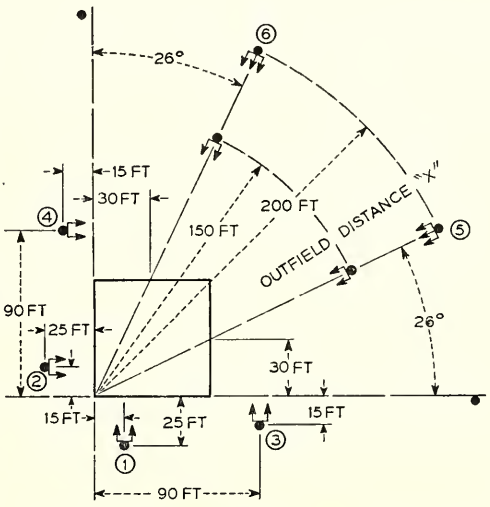


FIG. 12-16. Standard lighting layout for Class C softball fields.

INSTALLATION DATA

Outfield distance "x" (feet)	<150	150–200	
Pole number	①,②,③,④,⑤,⑥	①,③,④,⑤	⑤,⑥
No. 1,500-watt floodlights per pole	2	2	3
Mounting height (feet)	40	40	40

Tennis. Tennis is a fast, aerial, and low-play sport but it is confined to a smaller area than are baseball, football, and softball. Consequently, less equipment is required to provide the recommended illumination. Equal care is required to maintain the recommended quality. Where tournament play is contemplated, the layout of Fig. 12-4*a* should be followed in anticipation of considerable play well behind the base lines.[15, 16, 17, 18, 19, 23, 24, 32]

Where playground tennis or its equivalent is to be played, the four poles (Fig. 12-4*a*) marked A and B and floodlights thereon may be omitted, the application data being otherwise identical for single and multiple courts. A second satisfactory layout for playground tennis utilizes cable-suspended, industrial-type, high-bay or dome reflectors, 30 to 35 feet above ground, equipped with 1,500-watt lamps. Five reflectors suspended on a cable parallel to the center line of the service courts, with the center unit above the net and 20-foot spacing between units, have been found satisfactory.

Still better results satisfactory for tournament play will be obtained if two such reflector rows are used, each about 6 to 10 feet outside the court side lines (using wide-spread reflectors). This system is economical for multiple courts on which the caliber of play is high. In such installations visors or halfskirts are recommended on the outside of reflectors in the outer rows.[17, 23, 24]

Combination sports field. Many athletic fields are laid out for the daytime seasonal playing of several sports, usually for a two- or three-game combination of baseball, softball, and football. Each such combination requires special attention and the final electrical illumination design will be affected by the relative location of the several fields.[16, 18, 23, 24]

Where baseball and softball are played with the same home-plate and foul-line locations, the problem is likely to be simple. The baseball pole locations (and mounting heights) can be made entirely satisfactory for softball lighting, by means of a system (switching or other) that will permit lighting only as many floodlights as are necessary, and, properly aimed, to cover the softball area. Consequently, no special treatment is needed.

A great number of equipment locations is possible with overlapping baseball or softball and football fields. (See Fig. 12-17.) It will be noted that the use of 120 floodlights for a Semiprofessional class baseball field makes possible the design of the layout to play also softball and football without additional floodlights. It is necessary either to re-aim floodlights on certain poles between seasons or mount additional floodlights on those poles otherwise requiring re-aiming. A second method is to use floodlights with reflector assemblies detachable from the socket hoods or brackets. Certain bracket assemblies (with reflectors) then are adjusted for proper aiming for baseball. During football season, such reflector assemblies as are needed are removed from baseball brackets and placed on bracket assemblies already aimed for football. Mounting height on a pole should be the greatest height recommended for any sport served by that particular pole. It is sometimes necessary to provide portable or semiportable guyed poles for certain locations in order to avoid too great deviation from the standard layouts for one or more of the sports.

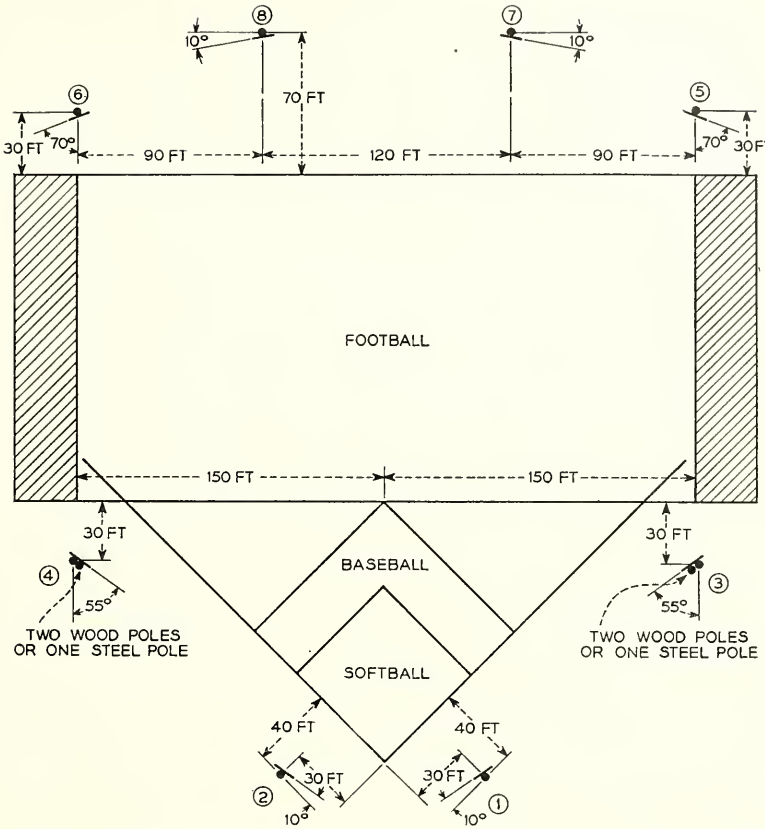


FIG. 12-17. Lighting layout for overlapping Semipro Class baseball, Class A softball, and Class A football fields.

Floodlight Installation and Operating Data

POLE NO.	MTG HGT (ft)	OPERATE ALL LIGHTS FOR BASEBALL			OPERATE LIGHTS AS FOLLOWS for Football			for Softball		
		Lights* per pole	Narrow Beam	Wide Beam	Lights* per pole	Narrow Beam	Wide Beam	Lights* per pole	Narrow Beam	Wide Beam
1	100	14	10	4	10	10	0	4	0	4
2	100	14	10	4	10	10	0	4	0	4
3	80	22	14	8	14	9	5	8	5	3
4	80	22	14	8	14	9	5	8	5	3
5	80	12	6	6	12	6	6	6	6	0
6	80	12	6	6	12	6	6	6	6	0
7	80	12	8	4	12	8	4	6	6	0
8	80	12	8	4	12	8	4	6	6	0
Total.....		120	76	44	96	66	30	48	34	14

* 1,500-Watt.

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40. "Floodlighting a Dog Track," *No. 21-12**.

* I. E. S. Lighting Data Sheet.

SECTION 13

TRANSPORTATION LIGHTING

The general principles of interior and exterior lighting set forth in Sections 10 and 11 are, for the most part, applicable in the transportation field. Some practical problems of great importance encountered in applying the principles to vehicles and the paths over which they travel appear to complicate the means of achieving desired results because, since they are of less consequence in other application fields, they are less familiar. For example, power-supply characteristics and capacities of automobiles, airplanes, and railway trains often make difficult and expensive the provision (by means of standard types of light sources) of interior illumination of recommended quantity and quality. The tremendous areas and the intermittent use of transportation pathways and their exposure to a wide variety of weather conditions are factors which should be considered carefully in applying the general principles in practical designs.

Lighting of Vehicles

Regardless of the vehicle, there are separate considerations for the lighting supplied primarily for passenger use, comfort, or safety, and that supplied primarily to assist the vehicle operator in the performance of his duties.

The following characteristics of vehicles, though not common to all types, are influential with respect to lighting:

1. Direct-current power supplies are commonly used because batteries are needed for stand-by operation and because of the desirable characteristics of d-c motor operation.
2. Equipment costs, fuel economy, space limitations, and similar factors call for highly efficient utilization of available energy.
3. Most vehicles have low ceilings.
4. Many vehicles are designed for mass production rather than custom construction.
5. In most vehicles the field of view of most occupants is fixed.
6. Individual passenger occupancy usually is of short duration.

AUTOMOBILE LIGHTING

Most automobiles depend on a three-cell (6-volt) wet storage battery, kept charged by a d-c generator driven by the car engine. The capacity of such a battery is limited although the demand for heaters, radios, and other special devices has materially increased the capacity in recent years. A single wire grounded wiring system is commonly used. (See Fig. 13-1.)

Illumination of Passenger Automobiles

Interior illumination. The average person does not expect to read or write continuously in a passenger automobile, either while driving or while the vehicle is parked. Therefore, installations have been planned to provide illumination for casual inspection of road maps and other printed

NOTE: References are listed at the end of each section.

matter, for safety in getting in and getting out, and to carry out the style motive of the car interior. The number of luminaires commonly used ranges from one to four, employing 6- to 21-candlepower lamps. Usually these are shielded so as to prevent direct glare. Standards of brightness and illumination have not been established for passenger automobiles.

Panel-board lighting for automobiles is designed to meet decorative as well as utilitarian requirements. Since the average driver uses the various meters for reference rather than for operation, the seeing problems are not critical. Illumination usually is provided by small lamps recessed behind glass, plastic, or other light-transmitting materials; by similar lamps used for the edge lighting of recessed or raised numerals; or by direct illumination from lamps at the top or bottom and in front of the panel faces. Ultraviolet excitation of fluorescent panels was employed in a standard automobile for the first time in 1946. Dimming control of panel numeral or pointer brightness is recommended.

Exterior illumination. The most important illuminating-engineering problem in the automobile field concerns head lamps. Because of the speed at which modern cars are operated, because most roads are used for two-way traffic, and because a few feet above the road surface is the most convenient head-lamp location, it is not easy to provide good road lighting without creating glare for an approaching driver. The standard method used today employs two filaments in a 7-inch bulb formed by joining a mirrored parabolic rear section with a lens front section, or a two-filament lamp in a hermetically sealed, 7-inch-lens-reflector combination. Consuming a total power of about 90 watts, the lower filaments of a pair of such lamps located at the optical centers of their respective reflectors produce together a maximum beam candlepower of about 65,000 (the permissible maximum is 75,000). Though the high-intensity portion of this beam is narrow (confined to a few degrees each side of the optical axes), careful control of the gradients provides illumination in ditches, for turning corners, and so forth.

Standardization of Automobile Lighting

The mass production methods characteristic of the automotive industry encourage extensive standardization and, through the co-operation of the Society of Automotive Engineers, the Illuminating Engineering Society, safety engineers, and state motor-vehicle administrators, standards have been developed over a period of years covering the characteristics and procedure for testing the following types of automotive-lighting equipment:

Head lamps
Head-lamp mountings
Headlight switching
Sealed-beam headlamps
Supplementary driving lamps
Supplementary passing lamps
Fog lamps
Stop lamps
Tail lamps
License-plate lamps
Direction-signal lamps
Clearance, side-marker, and identification lamps
Reflex reflectors
Electric emergency lanterns

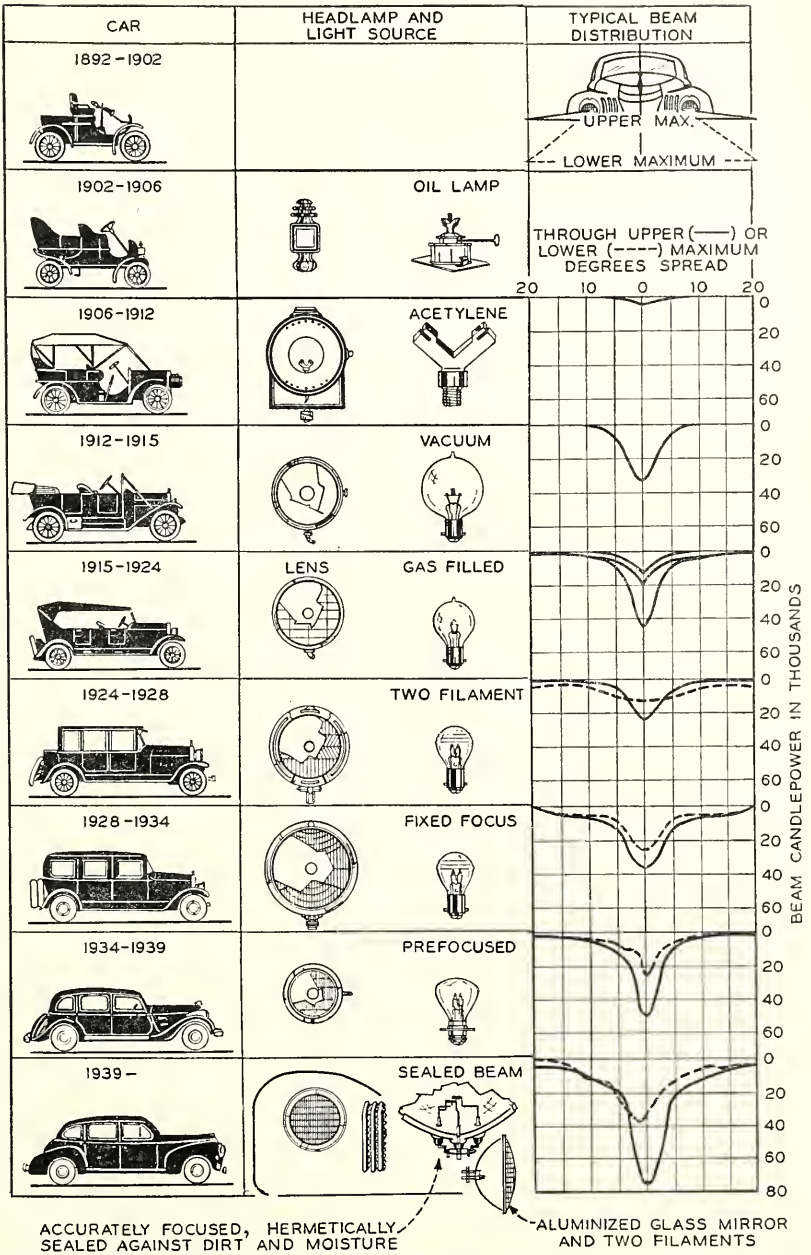


FIG. 13-1. Illustrated chart of automobile head lamp history, 1892-1947.

The data on pages 13–4 to 13–13 are from the joint standards and recommended practices of the Society of Automotive Engineers and the Illuminating Engineering Society as published in the 1947 *SAE Handbook*.

Electric Headlamps for Motor Vehicles

The study of automotive headlighting requirements dates back to 1914 when electric lighting first was applied to motor vehicles. The first joint Illuminating Engineering Society–Society of Automotive Engineers headlighting specifications were adopted in 1918 and were based on the idea of providing a single, all-purpose beam arranged so as to compromise between road illumination and glare. As operating speeds increased, as more cars appeared on the road, and as cars were provided with softer springs and lower drivers' seats, these and other factors tended to make lighting with single-beam lamps less satisfactory. Attention gradually shifted to the need for two beams, one aimed high enough to reveal obstacles and turns at a safe distance ahead and the other aimed low enough to avoid glare. As specified in the dual-beam specifications adopted in 1930, the driver was to be responsible for using the proper beam at the right time. The specifications for multiple beam headlamps of the asymmetric type were adopted in 1933. In 1936 the specifications were revised to cover all types of multiple-beam head lamps, and to comply with the *1936 SAE Headlighting Inspection Code for Motor Vehicles*. In January 1937 the entire specification including the location and values for photometric test points was revised to designate minimum laboratory optical test requirements for approval purposes. (See Fig. 13-1.)

Head lamp. A major lighting device used to provide general illumination ahead of a vehicle.

Auxiliary driving lamp. An additional lighting device on a motor vehicle used primarily to supplement the head lamps in providing general illumination ahead of the vehicle.

Multiple-beam head lamps. Head lamps which are arranged to permit the driver of a vehicle to use any one of two or more distributions of light on the road.

Clear road beams. One or more beams intended primarily for distant illumination and for use on the open highway when not meeting other vehicles.

Meeting or traffic beams. One or more beams low enough on the left to avoid glare in the eyes of oncoming drivers and intended for use in congested areas and on highways when meeting other vehicles within a distance of 500 feet.

As the headlighting art is a continually developing one, these specifications are necessarily of a current character and are subject to revision from time to time. They are applicable for use in connection with motor vehicle regulations by state or federal authorities having administrative powers but their inclusion in state or federal laws where the requisite flexibility of revision is absent should be discouraged.

Photometric Test Points

In locating photometric test points, the following nomenclature shall apply: The line formed by the intersection of the median vertical plane parallel to the lamp axes and the test screen is designated as V. The line formed by the intersection of the horizontal plane through the head-lamp centers and the test screen is designated as H. The point at the intersection of these two lines is designated as H-V. The other points on the screen are designated by similar symbols to indicate the number of degrees of arc above or below H and the number of degrees of arc to the left or the right of V, for example: ½D-3L is a point ½ degree below H and 3 degrees to the left of V, and ½U-3R is a point ½ degree above H and 3 degrees to the right of V. (See Fig. 13-2.)

Samples for Test

Sample head lamps representative of the type regularly manufactured and marketed shall be submitted to the laboratory for test. Such samples shall include all accessory equipment peculiar to the device and necessary to operate it in its normal manner, except that the socket sleeve may be omitted from the reflector. The samples shall be accompanied by suitable instructions for adjustment, sufficient to

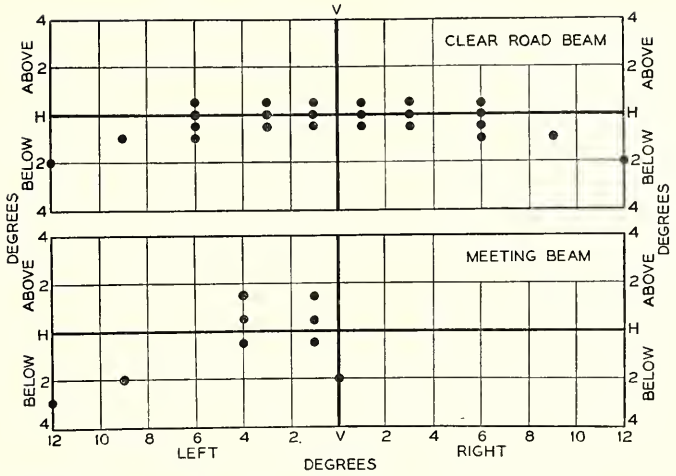


FIG. 13-2. Multiple-beam head lamp test point candlepower values (car one-half loaded).

enable the laboratory operator to locate the light source in its correct designed position and to aim the beams. The laboratory report shall include a copy of the instructions.

Lamps Used in Test

The lamps used in the tests, unless otherwise specified, shall be supplied by the laboratory. They shall be of standard manufacture and the type shall be specified by the applicant. They shall be of such character that they will give their rated candlepower when operated at approximately their rated efficiency. Photometric tests shall be made with the lamps operating at rated candlepower.

Required Test Data

Candlepower values shall be recorded for the five specified filament positions at each of the test points covered by the acceptance specifications that follow, and at any additional points needed to establish compliance with these specifications.

Specifications for Multiple-Beam Head Lamps

These specifications are based on the fact that assurance of reasonable safety in driving at night under present motoring conditions demands the provision of at least two beams of different characteristics under the immediate control of the driver, one arranged to reveal obstacles at a safe distance in advance of the vehicle under ordinary conditions of road contour and loading, and the other arranged to avoid dangerous glare under usual conditions of passing and when driving in congested areas. The driver is to be held responsible for using the proper beam.

Test Procedure

The light sources in the head lamps shall be located in the designed position as specified by the manufacturer. A photometer shall be set up at not less than 60 feet from the head lamps.

Aiming adjustments shall be made on one clear road beam only.

The head lamps' clear road beam shall be aimed so the vertical center of the zone of highest intensity falls at the horizontal line through the photometer axis.

The clear road beam of each head lamp shall be aimed laterally with respect to the single vertical line through the photometer axis in the same manner as the manu-

facturer specified said beam shall be aimed on the car with respect to a vertical line ahead of each lamp. Correction should be made for the difference between the distance from lamp to photometer and the distance from lamp to aiming screen specified in the manufacturer's instructions.

Where conventional bulbs with two-pin bayonet bases are used, candlepower tests shall be made with the light source at the designed positions and also in positions 0.060 inch above, below, ahead, or behind the designed position. If prefocused bulbs are used, the limiting positions at which tests are conducted shall be 0.010 inch added to the published tolerance of filament positioning for the prefocused bulbs used.

Each pair of head lamps shall be aimed only once for each position of the light source.

Candlepower Requirements for Laboratory Test

Test Point Values

(Car one-half loaded. See Fig. 13-2)

CLEAR ROAD BEAM*					
POSITION	CP MIN	POSITION	CP MIN	POSITION	CP MIN
½U—1R and 1L	15,000	H—3R and 3L	10,000	½D—6R and 6L	3,000
½U—3R and 3L	7,000	H—6R and 6L	4,000	1D—6R to 6L	3,000
½U—6R and 6L	3,000	½D—1R and 1L	15,000	1D—9R to 9L	2,000
H—1R and 1L	25,000	½D—3R and 3L	7,000	2D—12R to 12L	1,000
MEETING BEAM*					
POSITION	CP MAX	POSITION	CP MAX	POSITION	CP MIN
1½U—4L	1,000	½U—1L	4,000	2D—V	7,000
1½U—1L	2,000	½D—4L	4,000	2D—9L	2,000
½U—4L	2,000	½D—1L	7,000	3D—12L	1,000

* The maximum intensity of the beam at any point shall be 75,000 candlepower.

Sealed-Beam Headlamps for Motor Vehicles

Physical and Optical Requirements

These specifications apply only to the sealed-beam type of headlighting units. They cover the requirements for interchangeability and photometric tests of sealed-beam head-lamp units.

Sealed-beam unit. An integral and indivisible optical assembly with the name "SEALED BEAM" branded on the lens.

Country or upper beam. A clear road beam intended for distant illumination and for use on the open highway when not meeting other vehicles.

Traffic or lower beam. A beam low enough on the left to avoid glare in the eyes of oncoming drivers and intended for use in congested areas and on highways when meeting other vehicles within a distance of 500 feet.

Photometric Test

Photometric tests shall be made with the photometer at a distance of 60 feet from the lamps. Units shall be operated at their rated voltage during the tests.

The country or upper beam shall have a sufficiently well defined high-intensity area or hot spot to permit the aiming of both beams from the center of this area.

The upper beam from each lamp shall be aimed visually so that the zones of maximum intensity superimpose at the photometric test plate and so that the geometric center of the zone of highest intensity falls 0.6 degree vertically below the photometer axis.

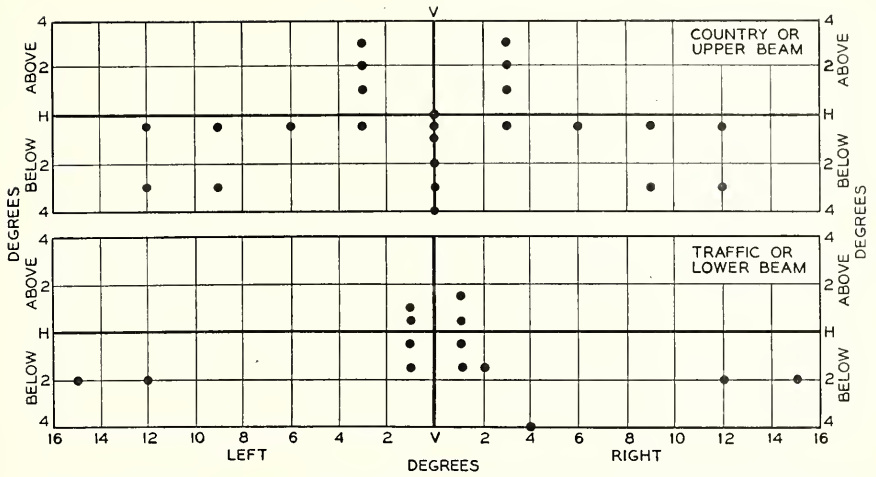


FIG. 13-3. Sealed-beam head lamp test point candlepower values (car unloaded).

COUNTRY OR UPPER BEAM

POSITION	CP MAX	CP MIN	POSITION	CP MAX	CP MIN
3U—to right and left	3,000	—	½D—6R and 6L	—	6,500
3U—3R and 3L	—	1,000	½D—9R and 9L	—	3,000
2U—to right and left	5,000	—	½D—12R and 12L	—	1,500
2U—3R and 3L	—	2,000	1D—V	—	35,000
1U—to right and left	8,000	—	2D—V	—	10,000
1U—3R and 3L	—	4,000	3D—V	—	5,000
H—V	—	25,000	3D—9R and 9L	—	3,000
½D—V	—	40,000	3D—12R and 12L	—	1,500
½D—3R and 3L	—	20,000	4D—V	10,000	—

TRAFFIC OR LOWER BEAM

1½U—1R to right	1,500	—	1½D—1R	—	10,000
1U—1L to left	800	—	1½D—2R	—	15,000
½U—1R to right	3,000	—	1½D—1L to left	6,000	—
½U—1L to left	1,000	—	2D—12R and 12L	—	1,500
½D—1R to right	6,000	—	2D—15R and 15L	—	1,000
½D—1L to left	2,000	—	4D—4R	25,000	—

The combined beams from the two lamps shall meet the following specifications:

Maximum beam intensity. The maximum intensity of the beam shall not exceed 75,000 candlepower.

Country or upper beam. To provide for manufacturing variations, a tolerance of plus or minus ¼ degree in location may be allowed for any test point. (See Fig. 13-3.)

Traffic or lower beam. To provide for manufacturing variations, a tolerance of plus or minus 20 per cent in candlepower and of plus or minus ¼ degree in location may be allowed for any test point. (See Fig. 13-3.)

General Requirements for All Types of Motor-Vehicle-Lighting Equipment

This standard covers the requirements and methods for laboratory tests, including vibration, moisture, dust, corrosion, color, and photometric tests. The types of

equipment to which it applies include:

Fog lamps	License-plate lamps	Clearance, side-marker, and identification lamps
Tail lamps	Direction-signal lamps	
Stop lamps	Electric emergency lanterns	Reflex reflectors

Samples for Test

Sample lamps submitted for laboratory test should be representative of the devices as regularly manufactured and marketed. Each sample should include all accessory equipment peculiar to the device and necessary to operate it in normal manner. Also, each sample should be mounted in its normal operating position on a supporting bracket designed to be bolted rigidly to the vibration rack. Dust and photometric tests may be made on a second set of unmounted samples, if desired, to expedite completion of tests.

Unless otherwise specified, lamps used in the tests should be supplied by the laboratory and should be representative of standard bulbs in regular production. They should be selected for accuracy in accordance with specifications approved by the National Bureau of Standards and should be operated at their rated mean spherical candlepower during the tests. Where special bulbs are specified they should be submitted with the devices and the same or similar bulbs used in the tests and operated at their rated mean spherical candlepower.

Vibration Test

A sample unit, as mounted on the support supplied, shall be bolted to the anvil end of the table of the standard vibration test machine and vibrated about 750 times per minute through a distance of $\frac{1}{4}$ inch. The table shall be spring mounted at one end and fitted with steel calks on the under side of the other end. These calks are to make contact with the steel anvil once during each cycle at the completion of the fall. The rack shall be operated under a spring tension of 60 to 70 pounds. This test shall be continued for 1 hour.

The unit shall then be examined. Any unit showing evidence of material physical weakness, lens or reflector rotation, or displacement or rupture of parts shall be considered to have failed.

Moisture Test

A sample unit shall be mounted in its normal operating position with any drain holes open, and subjected to a precipitation of 0.1 inch of water per minute delivered at an angle of 45 degrees from a nozzle with a solid cone spray. During the moisture test the lamp shall revolve about its vertical axis at a rate of 4 revolutions per minute. This test shall be continued for 12 hours. The water shall then be turned off and the unit permitted to drain for 1 hour.

The unit shall then be examined. Any accumulation of more than 1 milliliter of water in the unit, or warpage or shrinkage of the lens, shall constitute a failure.

Dust Test

A sample unit with any drain hole closed shall be mounted in its normal operating position, at least 6 inches from the wall in a box measuring 3 feet in all directions, containing 10 pounds of fine powdered cement in accordance with American Society for Testing Materials *Specifications for Portland Cement* (C150-42). At intervals of 15 minutes this dust shall be agitated by compressed air or fan blower by projecting blasts of air for a 2-second period in a downward direction into the dust in such a way that the dust is completely and uniformly diffused throughout the entire cube. The dust is then allowed to settle. This test shall be continued for 5 hours.

After the dust test the exterior surface only shall be cleaned, and if the maximum candlepower measured at this time is within 10 per cent of the maximum measured after the unit is cleaned both inside and out, it shall be considered adequately dust-tight.

Corrosion Test

A sample unit including mounting bracket, if any, shall be subjected to a 20 per cent salt spray solution for a period of 50 hours, consisting of two periods of 24 hours exposure and 1 hour drying each, at a temperature of 95 degrees Fahrenheit (35 degrees centigrade).

There shall be no evidence of undue or excessive corrosion immediately after this test has been completed.

Color Specification for Transmitting Mediums Used with Automotive-Lighting Equipment

The purpose of this specification is to provide standards for colors employed in motor-vehicle lighting equipment. It is intended to cover the colors of red, amber (yellow), and uncolored (white) transmitting mediums.

Red. Transmitting mediums which are to be classed as red must conform to the requirements for color specified below and may be examined for compliance with the requirements by comparison with a red limit glass. This glass has been prepared so that it represents the closest permissible approach to amber (yellow) and has at the same time the maximum purity of color. A red transmitting medium shall not be acceptable if it is paler or yellower than the light-limit standard glass when the two are illuminated by incandescent lamp light.

In case of doubt or samples close to the limit resort must be had to spectrophotometric determinations of the color of the sample.

Amber (yellow). Transmitting mediums which are to be classed as amber (yellow) must conform to the requirements for color specified below and may be examined for compliance with the requirements by comparison with amber (yellow) limit glasses. These glasses have been prepared so that one represents the closest permissible approach to red and the other the closest permissible approach to yellow-green, both having at the same time the maximum purity of color. An amber (yellow) transmitting medium shall not be acceptable if it is paler or greener than the light-limit standard, or redder than the dark-limit standard when the lens and the standards are illuminated by incandescent lamp light.

In case of doubt or samples close to the limit, resort must be had to spectrophotometric determinations of the color of the sample.

Uncolored (white). Transmitting mediums which are to be classed as uncolored (white) must not materially change the color of the source illuminating the mediums.

Trichromatic Coefficient Specification

The fundamental specification of these automotive colors expressed in terms of the standard observer, co-ordinate system and illuminant A (incandescent lamp operated at 2848 degrees Kelvin; $c_1 = 14{,}350$) adopted in 1931 by the International Commission on Illumination is as follows:

Red. For the purposes of these specifications, a red transmitting medium is a medium which when illuminated with I.C.I. standard illuminant A, transmits light for which

y is not greater than 0.335, and
z is not greater than 0.002

Amber (yellow). For the purposes of these specifications, an amber (yellow) transmitting medium is a medium which when illuminated by I.C.I. standard illuminant A, transmits light for which

y is not less than 0.398,
y is not greater than 0.429, and
z is not greater than 0.007

Uncolored (white). For the purposes of these specifications, an uncolored (white) transmitting medium is a medium which when illuminated by I.C.I. standard illuminant A, transmits light for which the values of x and y do not differ by more than 0.01 from the values x and y for the source illuminating the specimen.

Visual Comparison of Colors

A device which may be used for visually comparing the color of transmitting mediums used in automotive-lighting equipment and the limit glass or glasses is shown in Fig. 13-4. The visual color comparator consists of a lampholder capable of mounting and operating any standard bulb that is specified for such equipment. The bulb is so positioned that the light from it passes through the standard limit glass or glasses as well as diffusing glasses before being reflected from a mirror to the observer. The position of one of the diffusing glasses is adjustable so that by altering its position the brightness of these two portions of the field of view may be made the same. A similar diffusing plate and mirror are so positioned that the observer also views the automotive-lighting equipment being examined. The device is adjusted so that a brightness match is obtained between the test source and the limit glass beams. The color then is examined to determine conformance with the limits.

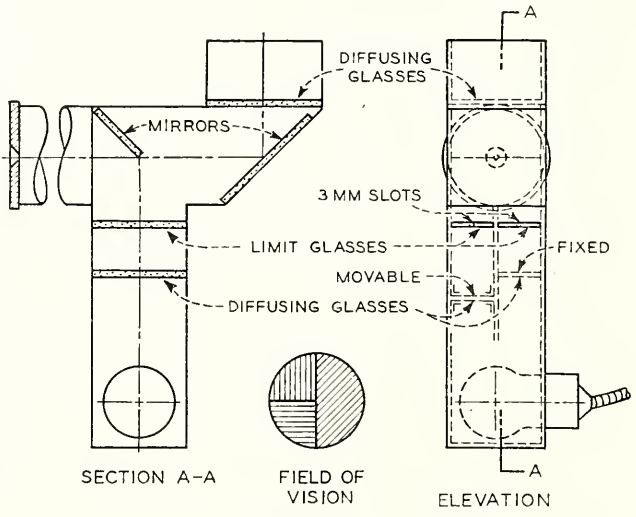


FIG. 13-4. Visual color comparator.

Headlighting Inspection Code

This code is intended only for the inspection and maintenance of headlighting equipment on motor vehicles that are in operation. The original code was drafted for use in preparing I.C.C. regulations for trucks and buses in interstate operation under the 1935 Motor Carrier Act. Subsequently it was the basis for Section 2 (Lighting Systems) of the American Standard D7—1939, *Inspection Requirements for Motor Vehicles.*

Single beam. A single beam provides only one fixed beam that is not adjustable from the driver's seat.

Multiple beam. A multiple beam provides two or more beams which may be selected by the driver.

Symmetrical beam. A symmetrical beam has both sides symmetrical with respect to the median vertical plane.

Asymmetrical beam. An asymmetrical beam is one in which both sides are not symmetrical with respect to the median vertical plane.

General Head-lamp Testing Requirements

Preparation for aiming. Before checking beam aim, the inspector shall see that no tire is noticeably deflated and shall rock the vehicle sideways. Beam aim shall be checked with no load in the vehicle other than the driver in the front seat. Faulty wheel alignment or improper tracking of the rear axle should be taken into consideration before the head-lamp inspection is made. Experience indicates that it is advisable to maintain the light output of the lamp well up toward the normal new-lamp value as indicated in the notes. The reference to higher standards mentioned in several of the notes in each case should be drawn to the attention of the car owner.

Screen. Beams should be inspected for focus and aim, either on a screen at a distance of 25 feet ahead of the head-lamps or with inspection equipment which gives essentially equivalent or more accurate results. If a screen is used, it should be of adequate size with a mat white surface well shaded from extraneous light and used on a flat level paved surface. Provisions should be made for moving the screen so that it can be aligned parallel with the rear axle, and a horizontal line drawn perpendicular from the center line of the screen will pass an equal distance between the two head-lamps.

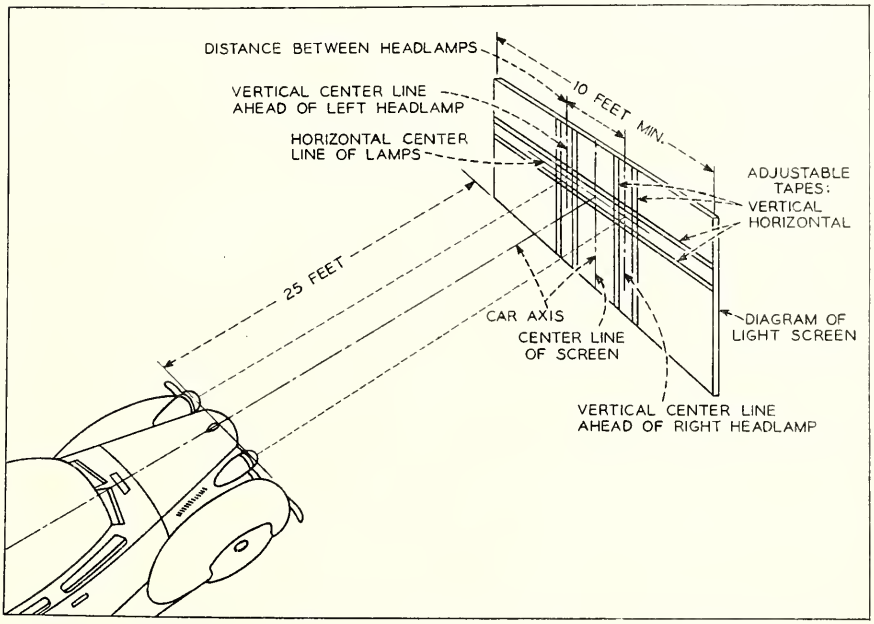


FIG. 13-5. Proper car position with respect to screen for headlighting inspection.

The screen should be provided with a fixed vertical center line and four laterally adjustable vertical tapes and two vertically adjustable horizontal tapes as shown in Fig. 13-5. The two movable horizontal tapes should be located on the screen at the upper and lower limits called for in the specifications with reference to the plane on which the vehicle rests, not the floor on which the screen rests. The four movable vertical tapes should be located on the screen at the left and right limits called for in the specifications with reference to center lines spaced to either side of the fixed center line on the screen by the amount the lamps are to the left and right.

Note 1. Vehicles in use today are equipped with two distinct types of head-lamp equipment—multiple- or selective-beam lamps and single- or fixed-beam lamps.

Single- or fixed-beam lighting generally is recognized as unsatisfactory because the beams must be aimed low enough to avoid glare to oncoming drivers, and therefore cannot give satisfactory illumination on the road.

Multiple-beam lighting includes a "traffic" or "meeting" or "passing" beam and an "open road" or "driving" beam.

Note 2. The inspector should see that the driver understands how to use the multiple-beam head lamps so as to obtain the best road lighting with minimum glare to other users of the highway.

General Lamp Inspection Limits

General lamp inspection includes the following types of lamp: head, rear, clearance, signal, marker, and adverse weather.

Any of the following defects shall be cause for rejection:

1. Any bulb in any lamp required by law or regulation or in any adverse weather lamp which fails to burn.
2. An improperly connected circuit which does not light the proper filaments for the different switch positions.
3. A cracked, broken or missing lens.
4. A lens that is rotated, upside down, wrongside out or is otherwise incorrectly installed.
5. A lens marked "left" or "right," not appropriately installed.
6. A multiple-beam, head-lamp lens, the name of which does not correspond with the name stamped on the lamp body.
7. A lamp which is not fastened securely to the vehicle.
8. A lamp showing a beam of color contrary to law or regulation.
9. Any defects in wiring or lighting equipment that would be likely to influence adversely the effectiveness of the lighting performance.
10. Any auxiliary equipment placed on, in, or in front of the head lamp which is not a part of the original standard equipment.
11. Beam indicator lights which do not indicate the proper beam to the driver and which do not operate satisfactorily.

Lamp output inspection. Approval shall be refused when the light produced by any head lamp or auxiliary lamp designed for use in place of a head lamp (whether measured in terms of maximum beam candlepower, average beam candlepower, lamp output, or other value) is less than 50 per cent of the normal new lamp value.

Note: A light output of 70 per cent or more of new lamp value, while not required in this Code, is desirable.

Lamp focus inspection. Focus inspection shall be made visually on a screen. Approval shall be refused when the beam from any head lamp or any auxiliary lamp is noticeably out of focus.

LAMP AIM INSPECTION

All of the following values are based on a 25-foot test distance. (See Fig. 13–6.)

Horizontal Beam Aim (Sideways)

Symmetrical beam. Upper beam. (All single-beam lamps, all double-beam symmetrical lamps, all adverse weather (fog) lamps.)

Asymmetrical beam. Upper beam. (Multibeam, Tribeam right lamp, Flexbeam left lamps.)

Approval shall be refused if the center of the high intensity zone is more than 6 inches to the right or left of straight ahead.

Note: A tolerance of not more than 4 inches, while not required in this Code, is desirable.

Asymmetrical beam. Upper beam. (Multibeam, Supersafe, Tribeam left lamp, Flexbeam, and Solar right lamp.) Approval shall be refused if the left edge of the stray light which is to the left of the high intensity zone extends to the left of straight ahead or is more than 6 inches to the right of straight ahead.

Note: A tolerance of not more than 4 inches, while not required in this Code, is desirable.

Vertical Beam Aim (Up and Down)

All beams from buses, coupés, roadsters, and long-wheel base cars should preferably be aimed near the upper limit. All beams from trucks and short-wheelbase, five-

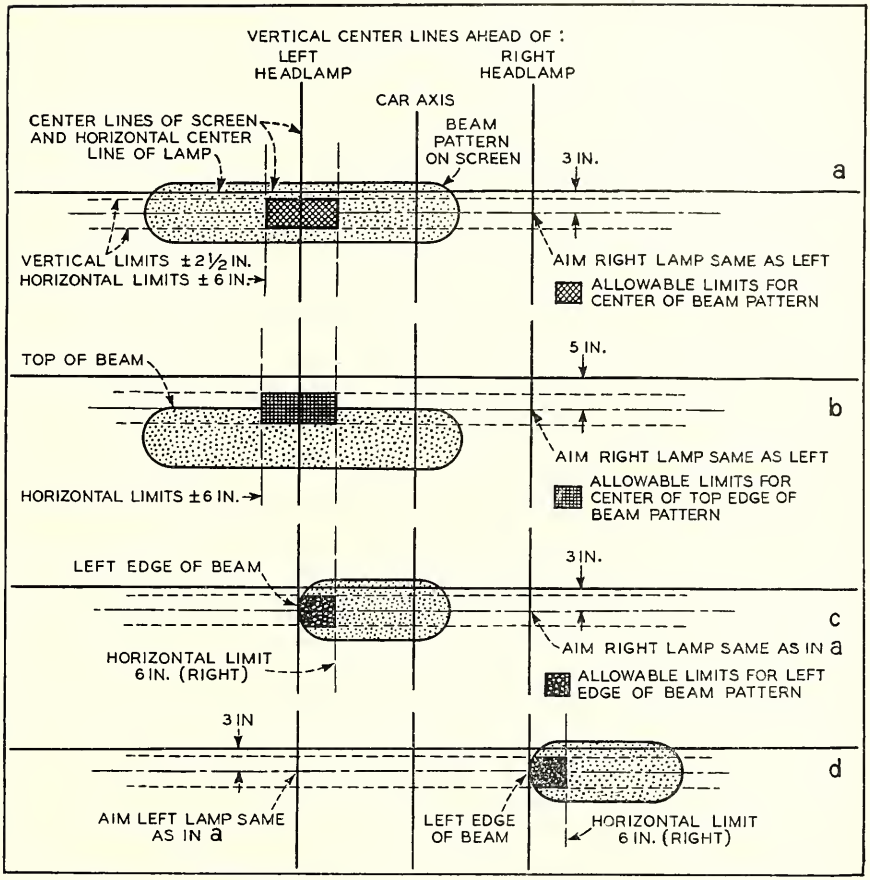


FIG. 13-6. Aim inspection guides for various types of lamps: a. All symmetrical two-beam lamps. b. All single-beam lamps. c. Asymmetrical beam lamps (Multibeam, Supersafe, Tribeam). d. Asymmetrical beam lamps (Flexbeam, Solar).

passenger cars should preferably be aimed near the lower limit, with no load in the vehicle other than the driver in front seat. With loaded trucks due allowance should be made for loading.

Multiple-beam headlamps. Upper beam. Approval shall be refused if the center of the high intensity zone is aimed higher or lower than 3 inches below the lamp center level. The tolerance applicable for this inspection shall be plus or minus 2½ inches.

Note: A tolerance of not more than plus or minus 1 inch, while not required in this Code, is desirable.

Single-beam headlamps. Approval shall be refused if the top of the beam from any single beam head lamp is aimed higher or lower than 5 inches below the lamp center level. The tolerance shall be plus or minus 2½ inches.

Note: A tolerance of not more than plus or minus 1 inch, while not required in this Code, is desirable.

Adverse weather lamps. Approval shall be refused if the top of the beam to the left of the prolongation of the extreme left side of the vehicle is aimed higher or lower than 4 inches below the lamp center level. The tolerance shall be plus or minus 2½ inches.

BUS LIGHTING

Operational illumination for motor buses is similar to that of private automobiles. However, in buses as well as in trains, planes, and ships interior illumination usually is required continuously during operation as a safety measure, for reading, for recognition and conversation between passengers, and so forth. Buses usually provide more room for batteries and generators than passenger cars and there is greater freedom in luminaire layout. Trolley-operated buses are not handicapped by a limited power supply.

An illumination level of 15 footcandles on the passenger reading plane is recommended. Passenger-controlled localized lighting is acceptable for inter-city buses. For safety a level of 5 footcandles is recommended on the aisle. The interior decoration should utilize high-reflectance surfaces in order to minimize the brightness ratios in the passengers' field of view. This is particularly important when local lighting is used to provide reading levels. The location and brightness characteristics of luminaires should be studied carefully so as to minimize both direct and reflected glare. (See Fig. 13-7.)

Despite the recognized advantages (low brightness, linear shape, shock and vibration resistance) of fluorescent lamps for bus lighting, the need for an a-c power supply is an obstacle to their immediate utilization.

Windshield reflections. In a motor bus as in many trolleys the operator sits in the same space as his passengers. This creates a problem in light distribution, since the immediate personal desires of passengers with respect to lighting do not coincide with those of the operator. Comfortable, useful, and attractive passenger space lighting may lead to glare and reflected images in the windshield.

To eliminate this glare windshields may be tilted outward (25 to 35 degrees) at the bottom so that none of the luminaires is imaged by the windshield in the operator's field of view. However, if the over-all interior illumination is quite high, there still may be annoying reflections from illuminated areas, from specularly reflecting handrails, window frames, etc., and from luminaires located quite near the operator. Opaque screens or curtains immediately behind the operator may be used as supplements to windshield tilting or, as on older buses, in place of it.

Destination sign. The usual destination sign is of the cloth roller curtain type, with white letters on a black background. It is illuminated at night by lamps mounted in the box at the rear of the roller curtain.

The following are recommendations for destination signs:

1. For 38-inch signs it is customary to use three 21-candlepower lamps mounted 14 inches apart. More uniform lighting of the sign will be accomplished by using four 15-candlepower lamps mounted 9 inches apart. If it becomes necessary to conserve power, three 15-candlepower lamps may be used with fair results. Signs illuminated by less than three 15-candlepower lamps are not satisfactory as they cannot be read at a distance.
2. Lamps should be located at least 6 inches to the rear of roller curtains

and on a level with the center of the sign. Lamps placed close to the sign produce uneven illumination which makes the sign difficult to read at a distance.

3. The interior of the sign box should be painted white or aluminum to increase the illumination on the sign, and help to produce an even light diffusion on the translucent letters.

4. The stroke of the letters should equal approximately 12 per cent of their height. The width of the letters should equal approximately 70 per cent of their height and the spacing between letters 20 to 25 per cent of their height. Letters 5 inches high are recommended. The specifications for width and spacing as given above are more important than letter height.

Rear sign. A sign bearing the name of the company and terminal cities similar to those displayed on the rear platforms of fast passenger trains often is used by intercity bus lines.

The sign usually is painted on a glass disk having a diameter of about 12 to 15 inches and is mounted at one end of a cylindrical metal box about 3 inches deep. The letters are translucent and lamps are mounted in the box to illuminate the sign at night.

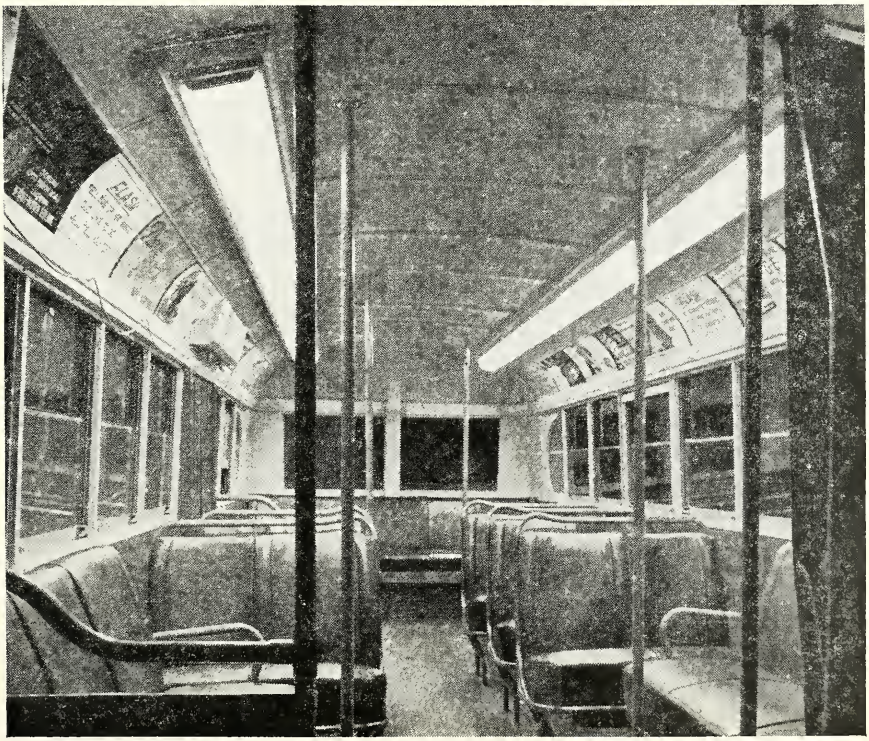


FIG. 13-7. Typical bus-lighting installation: Five footcandles on the aisle is provided for safety. High-reflectance surfaces and careful design and location of luminaires minimize brightness ratios and glare in the passenger field of view.

The glass disk is frosted on the inside, and the outside edge of the letters should be at least 1 3/4 inches from the border; otherwise, direct light from the lamps will cause spotty illumination. Five 15-candlepower or 6-candlepower lamps should be mounted in sockets equally spaced in the box. The color of the box interior and the proportions of letter size and spacing should be in accordance with the illuminated destination sign requirements.

Accessory lighting. Certain accessory lighting is required for the safe and satisfactory operation of a bus. *Step lights* provide the necessary safety for passengers entering or leaving. Occasionally an overhead step light operates in conjunction with the door. Slightly preferable, especially if the bus is otherwise well lighted, is the use of single or twin units recessed in the step well. If the latter do not operate automatically upon opening of the door, they should be shielded from the driver's field, since frequently they are designed with an upward component of light which might annoy him if it were always visible.

Stop and *tail* lights follow the general pattern of automotive requirements and usually are covered in detail by state law. The numerous stops made by a bus and the general use of power brakes make it advisable to exceed the requirements of law in the size, brightness, or number of stop lights installed if this is permitted.

Fare boxes require a small light to identify the slot or receptacle of the register; when tickets are used, it usually is necessary to provide overhead lighting in addition. Though occasionally this may be co-ordinated with the step lighting, it should not be operated automatically by the door, since the latter is closed when the bus is moving.

RAILWAY PASSENGER CAR LIGHTING AND LOCOMOTIVE HEADLIGHTS

Railway Passenger Car Lighting

Illumination levels in railway passenger cars increased during the decade 1935–1945 from 3 to 5 footcandles to 15 to 30 footcandles on the reading plane to keep abreast of the advances in other fields.

The trend in fixture design just prior to the beginning of World War II and also those fixtures being used in cars now under construction show a wide variety of taste and opinion on the part of designers.

Fluorescent lamps are being used in most new design work, since electric power on railway cars is limited. Fluorescent lamps offer the possibility for using the available energy efficiently because of their relatively high lumen-per-watt ratings as compared with that of incandescent-filament lamps. The following factors are considered advantageous for railway car service also:

The increased service life of fluorescent lamps tends to offset their greater initial cost. Linear sources enable designers to obtain a more pleasing and artistic effect within the car. Heat generated for a given footcandle value is less than in the case of incandescent-filament-type lamps and therefore tends to reduce the load on air-conditioning equipment.

Table 13-1 Comparison of Several Railroad Passenger Car Lighting Systems.

	FLUORESCENT					INCANDESCENT			
Power Supply	D-C	A-C				D-C			
Line Volts	60	118				30			
Nominal Wattage of Lamps	14	15	20	30	40	100	50	25	15
Lamp Designation	15 in. T-12	18 in. T-12	24 in. T-12	36 in. T-8	48 in. T-12	A-23	A-21	A-19	A-17
Watts input per lamp including control unit losses	23.4	19.5	24.5	36.25	49	100	50	25	15
Lamp output (lumens, 3,500° white)*	475	615	900	1,450	2,100	1,800	820	345	175
Approx. motor-alternator efficiency (per cent)	—	60	60	60	60	—	—	—	—
Approx. lamp regulator efficiency (per cent)	80	—	—	—	—	80	80	80	80
Battery output (watts per lamp)	29.25	32.5	40.8	60.4	81.67	125	62.5	31.25	18.75
Lumens per battery watt	16.2	18.9	22	24	25.7	14.4	13.1	11.03	9.35
Efficiency relative to 40-watt, a-c fluorescent	63	73.5	85.5	93.5	100	56	51	43	36.4
Number of lamps required to furnish equal footcandles relative to 40-watt, a-c fluorescent	4.4	3.4	2.3	1.45	1.0	1.17	2.56	6.09	12
Rated life (hours)*	1,500	2,500	2,500	2,500	2,500	1,000	1,000	1,000	1,000
Number of lamp replacements relative to 40-watt, a-c fluorescent	7.3	3.4	2.3	1.45	1.0	2.9	6.4	15.2	30.0

*Changes in the lumen output and life of the lamps will cause other items to change.

Variations in voltage affect the light output of fluorescent lamps only one-third as much as that of incandescent filament lamps.

Though the larger luminous cross section of fluorescent lamps makes it more difficult to control the distribution of their output, their large area and relatively low brightness minimize the need for control.

System efficiencies. Table 13-1 shows that because of the low efficiency of d-c operated, 14-watt fluorescent lamp systems, their efficiency relative to that of a-c operated, 40-watt fluorescent lamp systems is 63 per cent. The 1,500-hour life of the d-c operated, 14-watt lamp added to the greater number required means that about 7.3 d-c operated, 14-watt lamp replacements can be expected for every a-c operated, 40-watt lamp replaced. In addition, the larger number of connectors and receptacles increases the cost of installation and maintenance. It will be noted that as fluorescent lamp length and incandescent lamp wattage are increased, the relative system efficiency increases. Since the comparisons depend on the lumen output and life of each type of lamp, when changes are made in these characteristics the balance may shift in favor of one type or another.

Installation plans and luminaire characteristics. Lighting systems used in railway cars are of the direct, indirect, or semi-indirect type.

Direct-lighting systems may consist of a series of luminaires located along the center line of the car ceiling or of rows along either side of the car directly above the seats as shown in Fig. 13-8. In certain instances the general lighting system is supplemented by luminaires located in the bottom

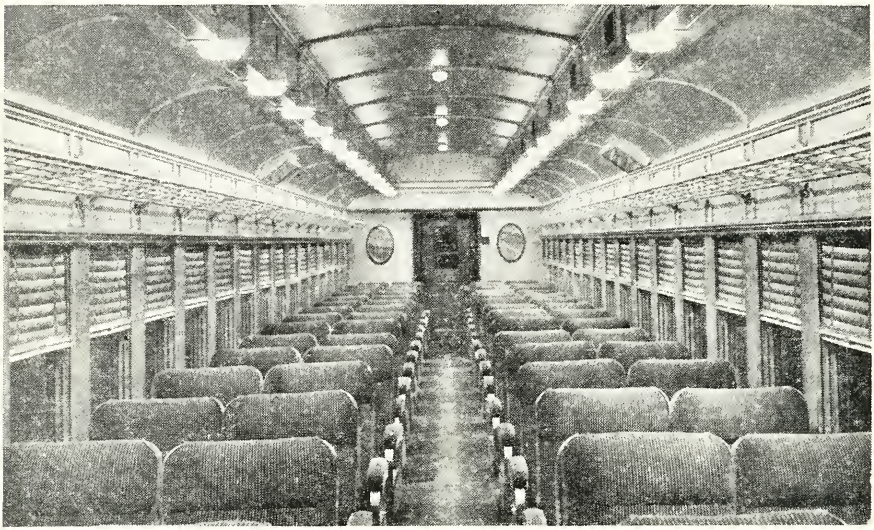


FIG. 13-8. A remodeled coach, relighted and airconditioned. A luminaire enclosing a 40-watt, incandescent-filament lamp installed over each transverse seat provides 10 footcandles on the passenger's reading matter.

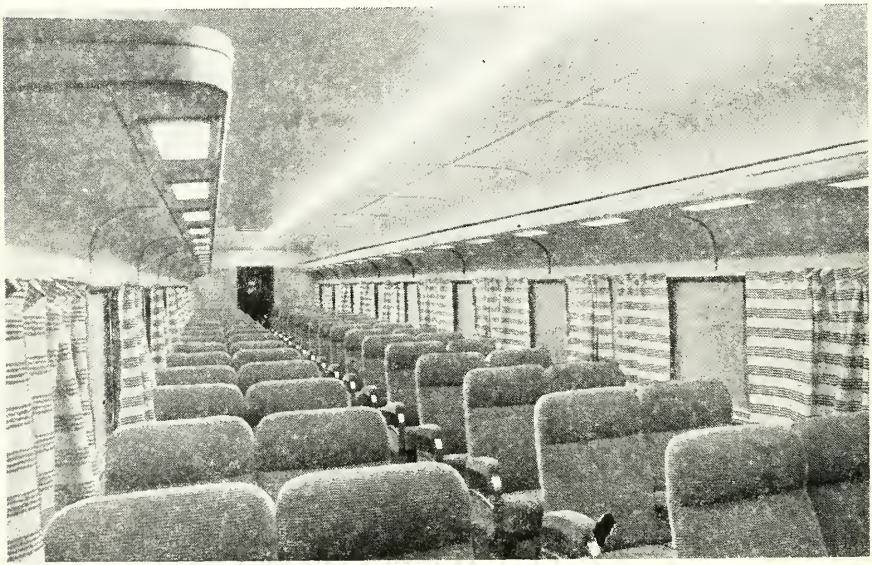


FIG. 13-9. General illumination provided by the centered panel in this car is supplemented by light from the individual luminaires seen in the luggage rack.



FIG. 13-10. The indirect-lighting system in this coach utilizes 30-watt fluorescent lamps installed in ceiling troughs.

of the luggage racks as shown in Fig. 13-9. In some cases it is desirable to provide individual switch control of luggage-rack luminaires.

Indirect lighting may be accomplished in a variety of ways. Continuous troughs built into the ceiling and located either along the center line or in rows directly above the seats is the usual design. This type of system is the least efficient initially and depreciates rapidly since dirt collects upon the reflecting surfaces and lamps. See Fig. 13-10.

Semi-indirect systems such as shown in Fig. 13-11 have been developed also. The continuous cylindrical plastic shell located approximately 18 inches below the luggage rack encloses two 30-watt, T-8 bulb, preheat start fluorescent lamps. The upper portion of the shell is clear. The lower portion is of Louver-plas (a trade name). The window louvers incorporated in the window sash directly above the electrical-lighting system transmit daylight without annoying glare.

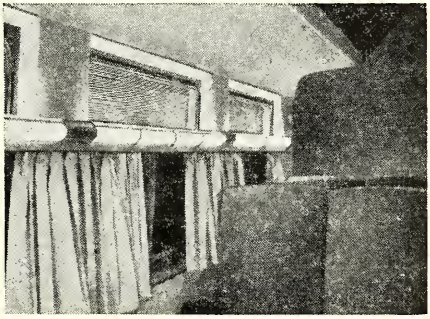


FIG. 13-11. This semi-indirect lighting system utilizes a cylindrical plastic shell luminaire with clear top and louvered bottom and sides. The bottom of the baggage rack reflects the indirect component.

Remodeling old cars. Where old cars have been modernized by the railroads some have been provided with incandescent lighting throughout. In general, such installations utilize individual fixtures arranged in two rows so that one lamp and fixture is located above each two-passenger seat. So-called dust-tight fixtures have replaced the former open-bottom glass shade.

A night-lighting circuit extending along the center line of the car ceiling provides illumination for safe passage through the aisles and also permits collection of tickets on overnight runs when the main general-lighting system is not operated. Enclosing luminaires, either of the lens or diffusing type, are employed as shown in Fig. 13-8.

Sleeping cars. The lighting of sleeping cars has undergone numerous changes in recent years. Modern berth and bedroom arrangements call for entirely different treatment, so far as lighting is concerned. Berth lighting presents an extremely difficult problem in that satisfactory light distribution must be provided for passengers reading in both reclined and seated positions. Illumination should be provided for two passengers at each seat and at the same time it should not produce glare when viewed by passengers in other sections of the car. The use of a 25-watt, inside-frosted, tubular lamp operated behind a glass lens having a circular diffusing area around it as shown in Fig. 13-12 has been found satisfactory. A small 6-watt, blue-bulb lamp also is provided in the fixture for night lighting.

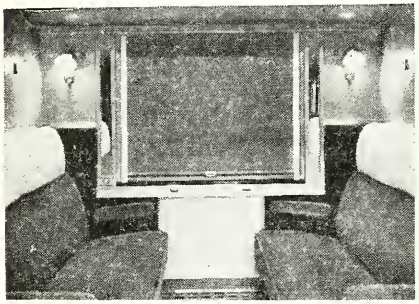


FIG. 13-12. This remodeled sleeping car is lighted by means of adjustable wall-mounted luminaires with a directional distribution controlled by an anodized aluminum reflector and convex lens.

Bedroom lighting is accomplished by similar tubular lens-type luminaires located directly above the head of the bed. General illumination throughout the room is supplied from round lens-type luminaires, mounted flush with ceiling surface. Fifty-watt, inside-frosted, incandescent-filament lamps are used.

In some recently built cars 20 to 25 footcandles of general illumination is provided by a centrally located luminous element lighted by instant-starting fluorescent lamps.

Power sources. Most railway passenger cars are equipped with a d-c generator, which is either belt or gear driven by one of the car wheel axles. Lead or nickel-iron storage batteries are floated on the line to provide stand-by power when the car is not in motion. Nominal voltages are 30, 60, or 115 volts. These voltages are maintained within narrow limits by means of a "lamp regulator."

The output of such generating systems ranges from 2 to 20 kilowatts. Typical schematic diagrams are shown in Fig. 13-13.

In some instances power may be supplied by what is termed a head-end system. In a head-end system a generator located on the locomotive energizes a circuit extending the length of the entire train. A three-wire loop system usually is required to balance the voltage throughout the train.

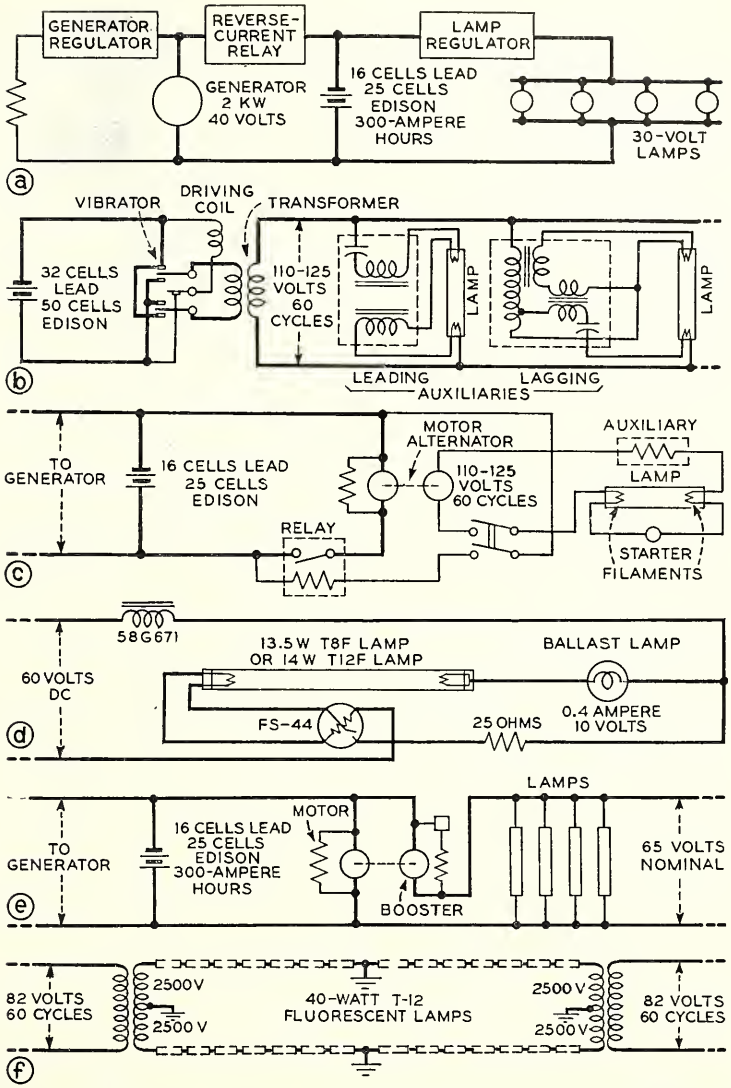


FIG. 13-13. Typical railway car electrical circuits: a. Schematic diagram of axle-generator system. b. Usual circuit for "constant load" vibrator inverter. c. Typical connections for motor alternator. d. Circuit arrangement for operating fluorescent lamps on 60-volt, d-c systems. e. Schematic diagram for booster circuits to provide direct current for operation of fluorescent lamps from conventional 30- to 40-volt, battery-generator systems. f. Circuit connections for operating fluorescent lamps in series on high-voltage, a-c systems.

A more recent development employs an a-c generator driven by a small internal-combustion engine installed beneath each car. In such installations batteries are not used. Voltages range from 115 to 230 volts.

Most railway-car, fluorescent-lighting installations use power from either alternators or vibrator inverters which convert 30-volt direct current to an alternating current suitable for fluorescent lamp operation.

Some installations recently placed in service utilize the 14-watt, T-12 fluorescent lamp operated on 58 to 62 volts direct current. A small filament ballast lamp is wired in series with it. A thermal-type starter switch is employed also. A lamp circuit regulator is required to maintain the voltage within the 58- to 62-volt range. Practical d-c operation is limited to the 14-watt lamps since voltages greater than 62 volts are required for the larger sizes.

Where only a 30-volt, d-c supply is available, a rotating "booster" delivering approximately 60 volts to the lamp has been used with satisfactory results.

Car platforms. In most cases, incandescent filament lamps (usually 25-watt rating) contained in concentrating enclosing fixtures are used directly above the car steps on platforms as shown in Fig. 13-14.

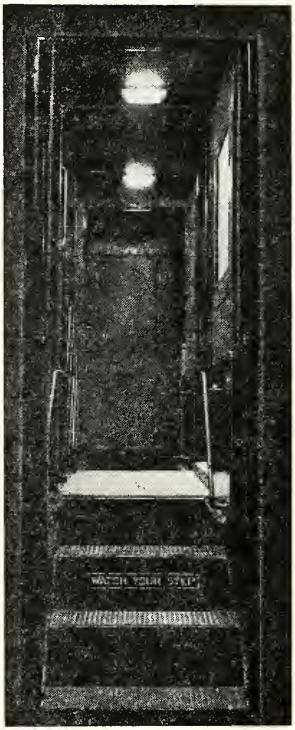


FIG. 13-14. Passenger-car platform and steps illuminated by a recessed luminaire with narrow beam spread.

Locomotive Headlights

To a large extent locomotive headlights are custom-built and specially equipped electrically for the types of locomotives on which they are used. They are powered by auxiliary steam-driven d-c generators (usually 32 volt), or from the d-c main power plant on Diesel-electric locomotives which may make 12, 32, 60, 75, or 110 volts available to the headlight lamp. A 14-inch-diameter reflector is used in most headlights. A representative 250-watt headlight (Fig. 13-15) exhibits a beam width of 8 degrees (as measured to 10 per cent of its maximum candlepower). The Interstate Commerce Commission rule that governs the headlight output of a road locomotive is that it shall make the figure of a man visible at a distance of 800 feet on a clear night. Switch engine headlights are required to provide a 300-feet pickup distance. Representative headlight axial beam candlepowers range from 300,000 to 400,000.

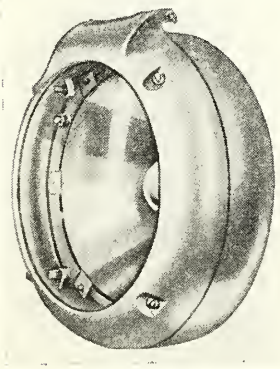


FIG. 13-15. Typical 250-watt locomotive head lamp.

AIRPLANE LIGHTING

Most contemporary passenger-airplane interior illumination is powered by a 24 volt rating, d-c supply. Occasionally, other power supplies providing 120 volts at 400 cycles are utilized. In most other respects the principles of bus lighting discussed on page 13-14 are directly applicable to the passenger space. (See Figure 13-16.) Because both weight and space are critical in airplane designs even more than in buses, efficiency is more important.

Exterior operational lighting for airplanes is controlled by the Civil Aeronautics Administration, and is related to the airport illumination standards described on page 13-43.

Airplanes are identified by flashing wing tip and tail lights. Individual landing lights, similar to sealed-beam automobile head lamps but larger



FIG. 13-16. Reading light illumination in typical multiengine passenger airplane.

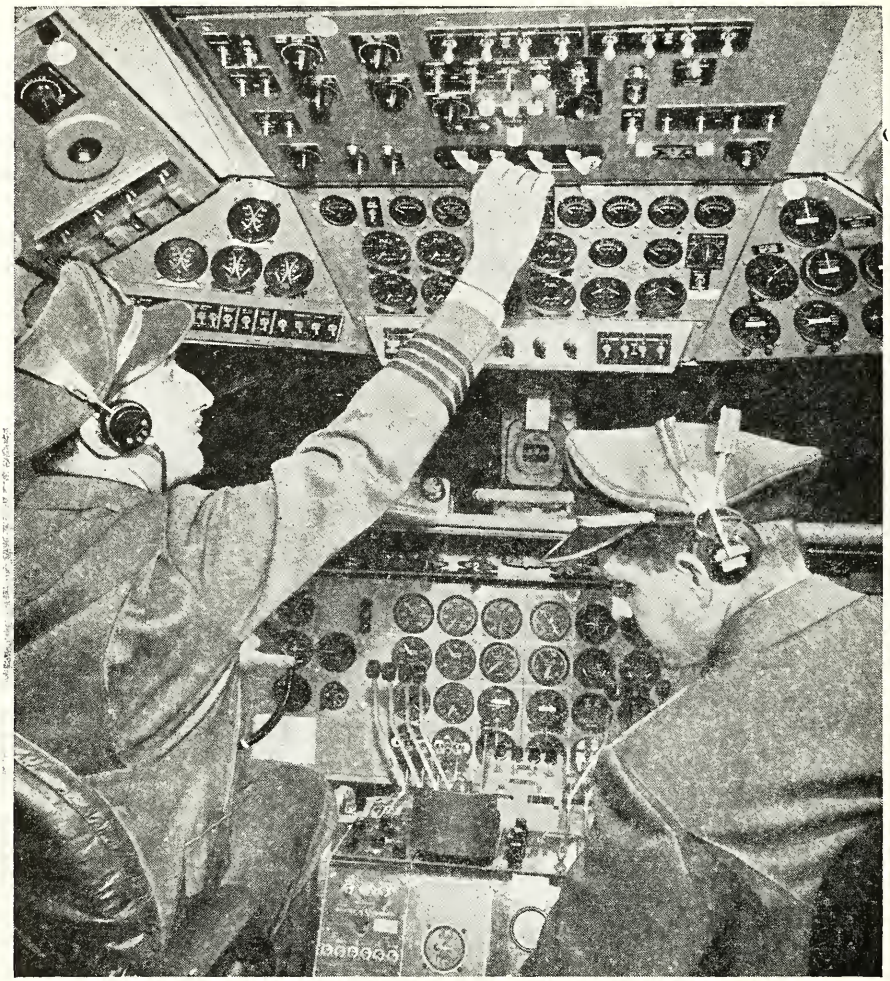


FIG. 13-17. A multiengine airplane instrument and control panel.

in diameter and higher in candlepower, are used to supplement airport illuminations during landing, taxiing, or take-off. (See Fig. 13-18.)

Multiengine, high-speed-aircraft pilot compartments are equipped with extremely complicated meter and control panels. The panels and instruments are carefully designed and arranged for maximum utility and visibility. Space, weight, and power limitations make the design of panel lighting an exacting task. (See Fig. 13-17.)

The necessity in some instances for maintaining pilot's dark adaptation and in military aircraft for limiting the visible range of any light visible from outside the plane introduces another difficulty. During World War II ultraviolet radiation was used to excite fluorescent and phosphorescent instrument dials and needles in some military aircraft. Red illumination has been used for cockpit and panel lighting also.

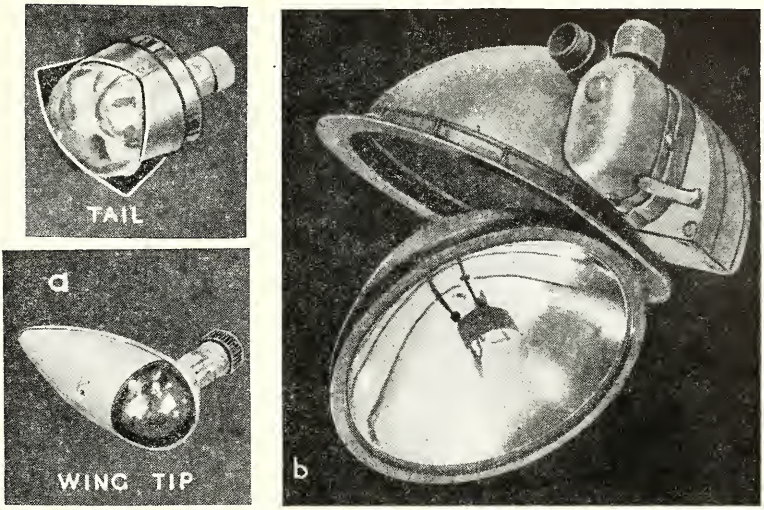


FIG. 13-18. Exterior illumination for aircraft: a. identification lights. b. retractible landing light.

LIGHTING OF SHIPS

On passenger and merchant ships illumination design is relatively free of the equipment size, weight, and power requirement limitations that apply to other means of transport. Occupancy areas approach in size those encountered ashore. However, ceiling heights usually will be less and operation in heavy weather at sea imposes high stresses and shocks on all equipment firmly attached to the ship's structure.

In general the principles set forth in Section 10, 11, 12, and 14 for various interior and exterior areas ashore will be applicable aboard ship also. (See Fig. 13–19.) Lighting equipment for shipboard installation should resist corrosion.

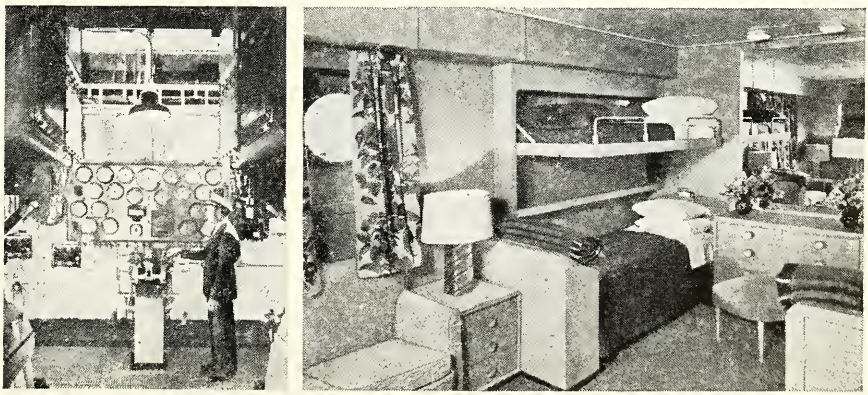


FIG. 13-19. Typical lighting installations on passenger and merchant ships are based on the same principles as installations for similar occupancy areas ashore.

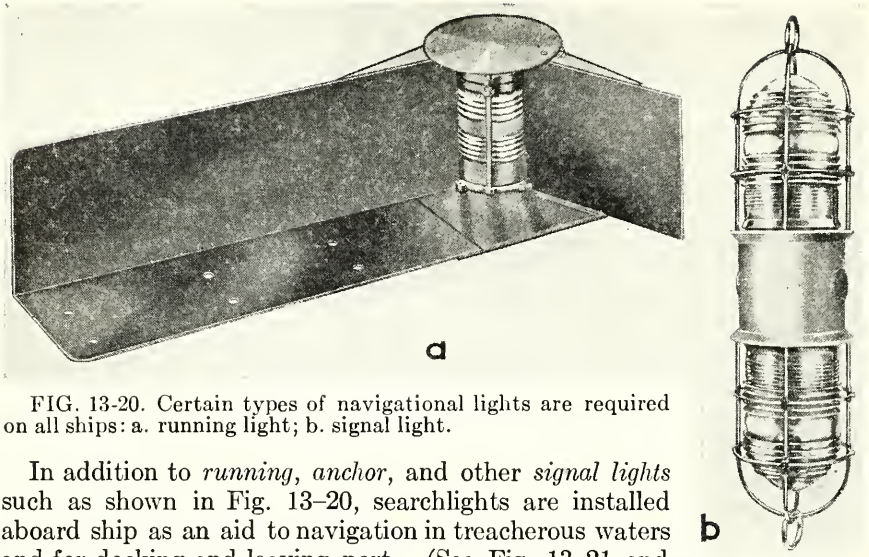


FIG. 13-20. Certain types of navigational lights are required on all ships: a. running light; b. signal light.

In addition to *running*, *anchor*, and other *signal lights* such as shown in Fig. 13–20, searchlights are installed aboard ship as an aid to navigation in treacherous waters and for docking and leaving port. (See Fig. 13–21 and Table 13–2.)

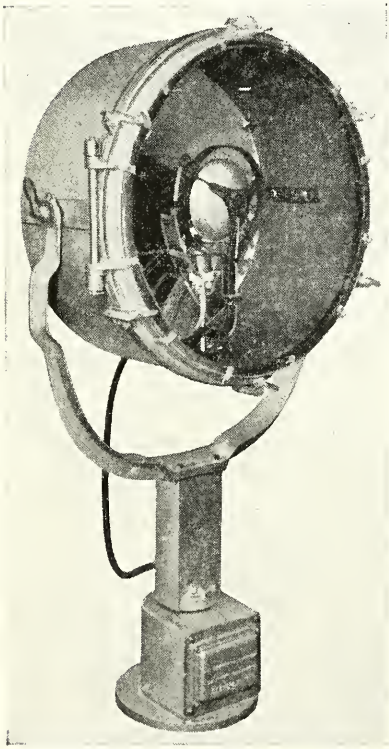


FIG. 13-21. A ship's searchlight

Searchlights installed on vessels of American registry and on vessels of foreign registry plying American ports are subject to the rules and regulations of the American Bureau of Shipping (A.B.S.) for certification of the vessel's eligibility for insurance issued by members of the Marine Insurance Underwriters (M.I.U.).

Searchlights installed on ocean-going *vessels of American registry* must have design, photometric, and constructional details approved by the Bureau of Marine Inspection of the U. S. Coast Guard before the vessel can be commissioned.

Searchlights installed on *vessels of American registry* must have an effective diameter not less than 18 inches, be designed for continuous operation with not less than a 1,000-watt incandescent lamp, and have a minimum beam candlepower of 2 million and a minimum beam spread of 5 degrees. Searchlights must be constructed entirely of corrosion-resisting materials

Table 13-2. Useful Range of Typical Ship Searchlights for Various Visibility Conditions

WEATHER CONDITION	MAXIMUM DAYLIGHT VISIBILITY RANGE OF TARGET	MAXIMUM ATMOSPHERIC TRANSMITTANCE PER THOUSAND YARDS (per cent)	INTERNATIONAL VISIBILITY CODE NUMBER	RANGE (Yards)*		
				12-inch	18-inch	24-inch
Exceptionally clear	Over 30 miles	Over 93	9	1,000	1,500	2,700
Very clear	30 miles	93	8	950	1,375	2,500
Clear	10 miles	82	7	900	1,250	2,250
Light haze	5 miles	68	6	750	1,000	1,900
Haze	2 miles	37	5	450	675	1,250
Thin fog	1 mile	14	4	225	340	625
Light fog	1,000 yd	2	3	140	200	375
Medium fog	500 yd	0.004	2	60	80	150
Heavy fog	200 yd	0.00005	1	8	12	20

* Based on good contrast brightness of target. Calculated from candlepower data, using formulas by Blondell, Breeding, Pennow, and Rey. Ranges are for targets having ½-degree visible angle, with target illumination of 0.1 footcandle. Twelve-inch searchlights are assumed to have 1-million, 18-inch searchlights 2-million, and 24-inch searchlights 7-million beam candlepower.

and must be completely nonmagnetic. With the latter movable magnetic objects cannot influence magnetic compasses.

Four types of mountings are specified: (1) Spot mounting, where the searchlight can be quickly detached electrically and mechanically from its moorings and quickly attached at any of several previously prepared locations. (2) Deck mounting, where the searchlight is mounted in a fixed position for local manual control. (3) Pilot-house, or wheel-house, control, the searchlight being mounted on top of the bridge and controlled by direct mechanical linkage from inside the bridge. (4) Remote control by cable, or by pneumatic or electrical means, where the searchlight is mounted a considerable distance from the control point.

In all cases the angular movement of the beam may not be less than 45 degrees above and below horizontal or less than 360 degrees in azimuth. Provision must be made so the beam spread can be increased quickly to not less than 20 degrees for search and rescue work.

Searchlights installed on *vessels limited to inland waterways, harbors, or intercoastal waterways* must be not less than 12 inches effective diameter, be designed for continuous operation with not less than a 500-watt incandescent lamp, and have a minimum beam candlepower of 400,000 and a minimum beam spread of 5 degrees.

Committees of the American Institute of Electrical Engineers and the National Electrical Manufacturers Association are working with Coast Guard officials on higher standards, particularly for Great Lakes vessels. Minimums of 16-inch diameter, 1,000-watts and 1-million beam candle power are being considered for the Great Lakes. On ocean-going vessels of 25,000 tons and over, minimums of 24-inch diameter, 2,000-watts, and 5-million candlepower are being discussed (1947).

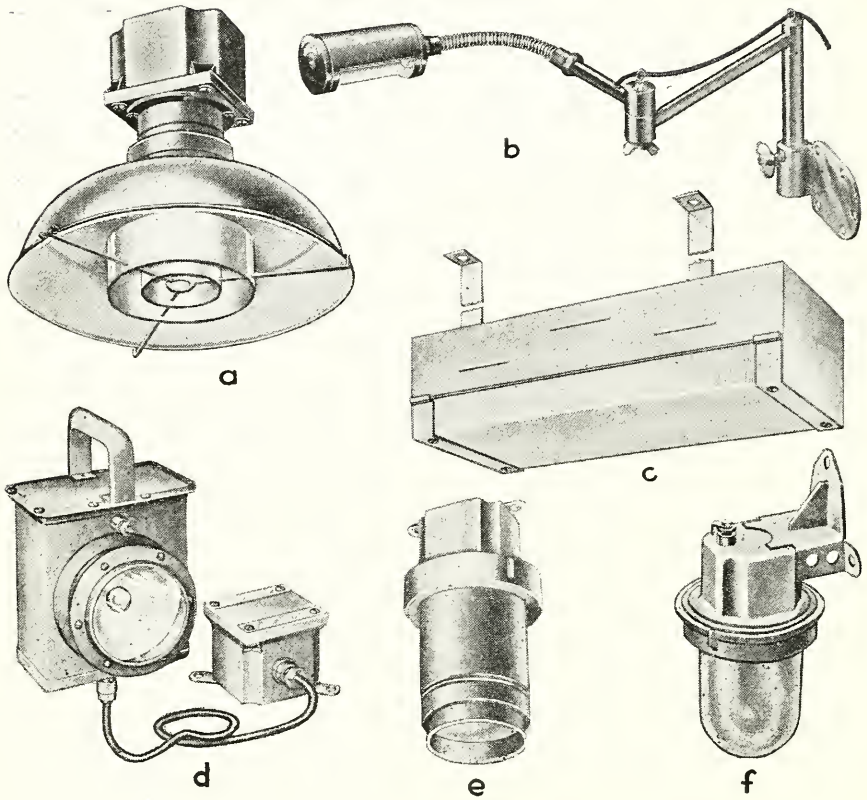


FIG. 13-22. A few of the lighting equipment designs standardized by the Bureau of Ships, U.S. Navy Department: a. louvered, industrial-type luminaire for overhead mounting. b. Adjustable chart-table luminaire for bulkhead mounting. c. Fluorescent-lamp luminaire with plastic diffusing enclosure. d. Relay-operated, battery-powered emergency hand-lantern. e. Blackout shield with red lens. f. Steamtight globe for bulkhead mounting.

Naval vessels are designed for specific military purposes which may place such a high priority on combative effectiveness measured in fire power, stability, and so forth that other factors such as lighting, though of recognized importance, are purposely designed for minimum weight and space with required effectiveness fixed at a minimum. To simplify naval logistics, designs are standardized throughout the service. (See Fig. 13–22.)

As in the case of military aircraft, it often is necessary to provide means for limiting the visibility of a ship during the day by means of camouflage, and at night by limiting the permissible brightness and color of its lights.

REFLEX DEVICES IN TRANSPORTATION LIGHTING

Retro-reflecting devices commonly called reflex reflectors are coming into more frequent use in transportation lighting and signaling. They first obtained wide acceptance as an adjunct to tail lamps on motor vehicles, affording stand-by protection in case of lamp failure.

Present-day improvement in materials and processes have so greatly increased their performance that reflex reflectors are now a standard device used to convey traffic control information at night on most highways. They are being used also in several types of railroad, marine, and aviation signaling, and in night display advertising. Some of the applications include:

Reflector flares for marking highway emergencies. (Permissible instead of pot torches or electric lanterns.)

Railroad switch signals. (Taking the place of oil lanterns.)

Clearance markers for commercial vehicles.

Luminous warning and direction signs.

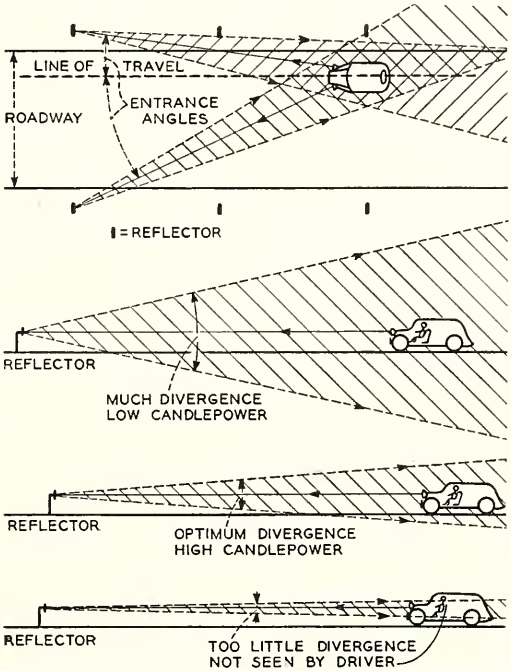


FIG. 13-23. Effect of the divergence of reflex devices on their angular coverage and intensity.

Regularly spaced delineators outlining horizontal and vertical highway contours, etc.

Luminous buoy heads for river and harbor channels.

Contact markers for airplane landing strips when power is not available.

Bicycle markers, front and rear.

Apparel reflex for pedestrians and belts for traffic officers.

Luminous pavement striping.

Luminous advertising display signs.

Principle of Operation

There are a number of specific types of reflex devices, but the principle of operation is the same for all.

A reflex reflector by no means reflects light in all directions when illuminated. Rather, as shown in Fig. 13–23, each reflex unit projects a narrow beam directly back at the source or sources lighting it.

Except for the conservation achieved by confining the reflected beam to this narrow cone the reflex would not appear as a bright source. The narrower the cone within which the light is returned, the brighter the reflector will appear, provided the observer's eyes are within that cone.

The light is reflected back toward its source, whether or not that source is directly in front of the reflector. This basic characteristic of reflex devices may be contrasted with the type of reflection occurring at an ordinary plane mirror where light is returned toward the source only when the mirror is exactly perpendicular to a line connecting it with the source.

Two generic optical systems that perform the required functions have been developed for general use. They are triple reflectors and lens-mirror devices.

Triple Reflectors

Three plane mirrors arranged mutually at right angles, as in the corner

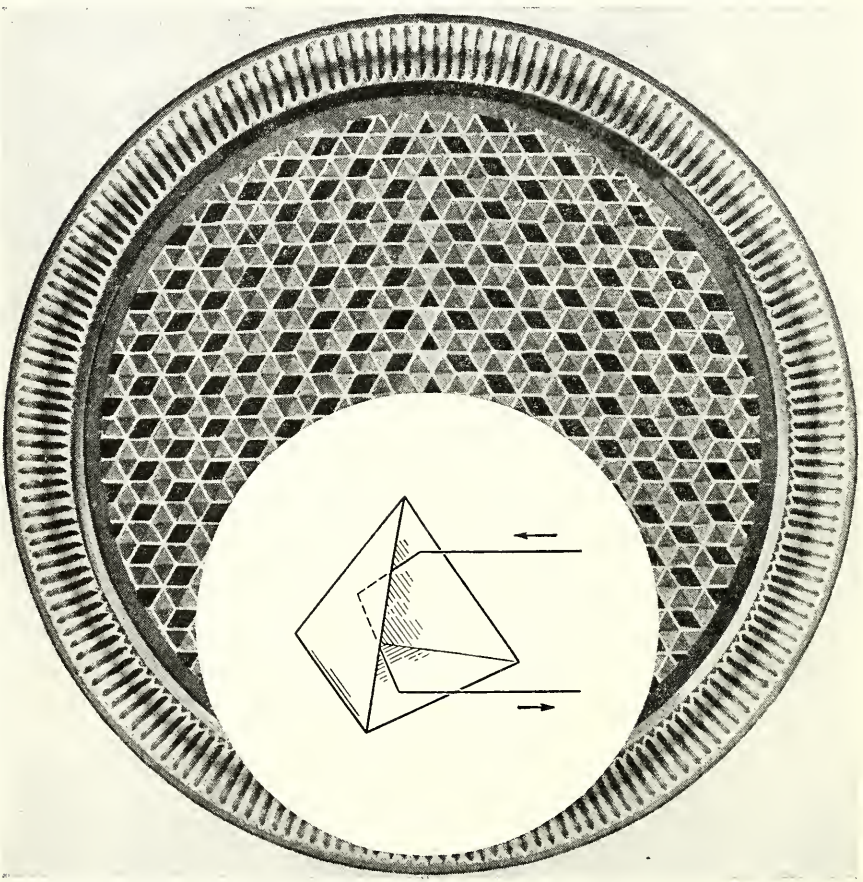


FIG. 13-24. Triple mirror reflectors comprise aggregates of concave cube corners.

of a cube, form a mirror system such that any ray of light which has been successively reflected from all three surfaces will be exactly reversed in direction. (See Fig. 13–24.)

This triple mirror becomes a reflex device in plate form by aggregating small concave cube corners in pressed glass or transparent plastic.

Pressed-glass triple reflex. Pressed cover glasses for tail lamps on automobiles are used in this convenient and economical place to combine the usual red lens and an area of aggregated cube corners. In case of lamp failure, the reflex action of the cube corners is an automatic substitute. A number of state regulations require the use of a reflex in this manner, and all motor vehicles have been so equipped since about 1935.

The difficulty encountered in pressing glass cube corners with a high degree of precision has limited the safety value of reflex devices of this character.

Plastic triple reflex. Acrylic plastic substitutes for glass reflex devices are now available. (See Fig. 13-25.) Triple reflector reflexes are now injection-molded, utilizing this material.

A high degree of precision in the formation of small cube corners can be maintained in production and a very narrow cone of reflected light is projected back to the source.

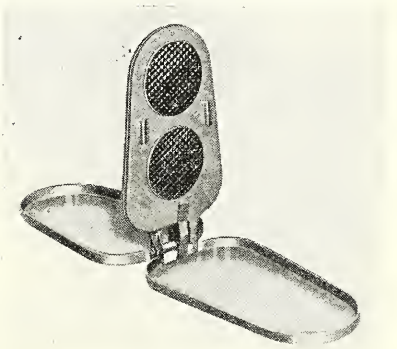


FIG. 13-25. Injection-molded plastic reflex used in a highway emergency marker flare.

Lens-Mirror Reflex

The other optical system that has received practical application as a reflex device is the lens-mirror "button." It consists of a short-focus-converging lens with a mirror conforming to its principal focal surface. (See Fig. 13-26.) This arrangement is similar to the optical system of the human eye. The mirror surface corresponds to the retina.

Reflex devices using the lens mirror principle are of three types: buttons, plaques, and spherical beads.

Individual buttons. Varying from $\frac{1}{2}$ to 1 inch in diameter, these usually are molded carefully from glass with some correction for both spherical and chromatic abberation. Made with the mirror surface sealed from the weather, these devices reflect a narrow cone of light, making them useful at long distances.

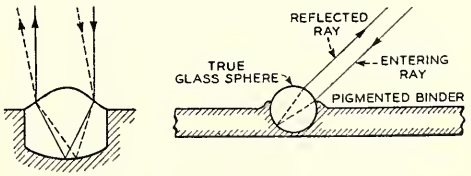


FIG. 13-26. Light paths in button and spherical ball type lens-mirror reflexes.

Pressed-glass, lens-mirror plaques. Aggregations of small lenses are pressed in the form of plates with a silvered back surface to form the focal mirror for the aggregation. Production difficulties limit the precision of these devices and therefore they are best used for short-range viewing when the observer and source are rather widely separated.

Spherical glass beads. Very small transparent spheres, no larger than coarse sand, and carefully graded for size, are embedded in a diffuse reflecting material such as white or aluminum paint. The reflecting coat may be carried on an adhesive cloth which is used to face signboards, or the glass beads may be pressed directly into a freshly painted signboard. A variation of this is the coating of freshly painted center stripes on highway pavements with glass beads.

STREET AND HIGHWAY ILLUMINATION

All aspects of traffic safety involve visibility. The fundamental factors which directly influence visibility are:

1. The brightness of an object on or near the roadway.
2. The size of an object and its identifying detail.
3. The contrast between an object and its surround.
4. The time available for seeing an object.
5. Glare.

Good visibility on street or highway at night may be provided by the quality of light which results in adequate pavement brightness with good uniformity and appropriate illumination of adjacent areas, together with reasonable freedom from glare.

The two principal methods of discernment in street and highway lighting are by silhouette and by surface detail.

Classifications of Urban Streets

The common factor in all street and highway safety considerations is the volume of vehicular and pedestrian traffic. As traffic volume increases the exposure to accident also increases. Good visibility is difficult to achieve in the confusion of moving vehicles and pedestrians. Yet accident hazards must be discerned against this background. Therefore it is of prime importance that a street or highway lighting system be built up from a definite plan based on a comprehensive traffic survey of all roadways under consideration. (See Table 13-3.)

Table 13-3. Institute of Traffic Engineers Street Classifications

CLASSIFICATION OF TRAFFIC	NUMBER OF VEHICLES PER HOUR (Maximum Night Hour, Both Directions)
Very light traffic	Under 150
Light traffic	150– 500
Medium traffic	500–1,200
Heavy traffic	1,200–2,400
Very heavy traffic	2,400–4,000
Heaviest traffic	Over 4,000

It is recommended that all streets be further classified by the volume of pedestrian traffic in the maximum night hour as follows:

Light or no pedestrian traffic: As on streets in residential or most warehouse areas and on express, elevated, or depressed roadways.

Medium pedestrian traffic: As on secondary business streets and some industrial streets.

Heavy pedestrian traffic: As on business streets.

Discernment

Silhouette discernment. An object is discerned by silhouette when the general level of brightness of all or a substantial part of it is lower than the brightness of its background. This method of discernment predominates in the observation of distant objects on lighted streets and highways. Silhouette discernment depends on the pavement surface reflectance. The recommended illumination levels given in Table 13-4 are based on 10 per cent pavement reflectance.

Discernment by surface detail. When an object is seen by virtue of variations in brightness or color over its own surface, without regard to its contrast with its background, it is discerned by surface detail.

Glare

The effects of glare are to reduce visibility and to cause ocular discomfort.

A generally recognized means of minimizing the effect of glare on visibility is to install luminaires well above the street level in order to remove them as far as practicable from the visual axis. The effect of mounting height on glare is illustrated in Fig. 13-27.

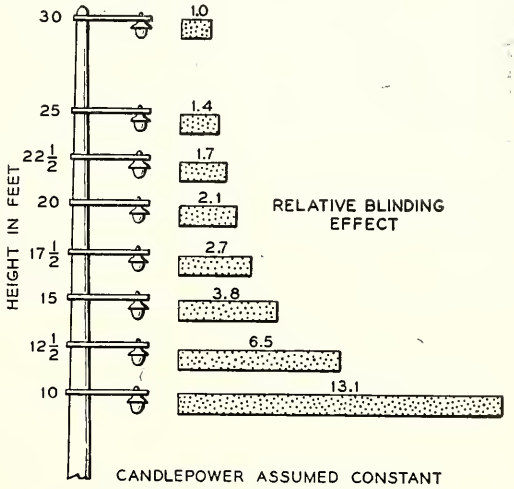


FIG. 13-27. Relative blinding effect of glare from luminaires mounted at various heights above a street.

Illumination Uniformity

Uniform illumination is a requirement of good street and highway lighting. On streets in the light to heaviest vehicular traffic classification, the lowest footcandle value at any point should not be less than one-fourth the recommended average values given in Table 13-4. On streets carrying very light vehicular traffic, the ratio between average and lowest footcandles at any point may be of the order of 10 to 1. For highway lighting the illumination at any point should not be less than one-fourth

of the values shown in Table 13-5. Table 13-5 gives the illumination recommended for highway lighting.

Table 13-4. Recommended Average Horizontal Footcandles (Lumens per Square Foot) for Urban Streets

PEDESTRIAN TRAFFIC	VEHICULAR TRAFFIC CLASSIFICATION			
	Very Light (Under 150)	Light (150–500)	Medium (500–1200)	Heavy to Heaviest (1,200 up)
Heavy	*	0.8	1.0	1.2
Medium	*	0.6	0.8	1.0
Light or none	0.2	0.4	0.6	0.8

* This condition is unusual, but if it should occur, the footcandle figure appearing in the column to the right may be used.

The following notes apply to this table:

1. The recommended footcandle values are the minimum average values on the roadway between curbs. On streets carrying from light to heaviest traffic, the lowest footcandle value at any point should not be less than one-fourth of the above values. On streets carrying very light vehicular traffic, the ratio between average and lowest footcandles at any point may be of the order of 10 and produce satisfactory results.
2. In general, satisfactory illumination on the sidewalk will be provided by lighting systems which provide the above recommended street illumination. However, visibility on the sidewalk should be given adequate consideration when selecting luminaires.
3. The achievement of satisfactory visibility by silhouette discernment depends on good pavement brightness which in turn depends on the reflectance of the pavement surface. The values in Table 13-3 are based on pavement reflectance of the order of 10 per cent. For the streets and traffic conditions in which silhouette discernment is importance, allowance must be made for pavement reflectances that vary from the favorable conditions assumed above. When reflectance is poor (of the order of 3 per cent) the illumination recommended should be increased 50 per cent. When reflectance is unusually high (20 per cent or more) the recommended values may be decreased 25 per cent. In general, these corrections will apply more specifically to streets carrying a light traffic volume where the illumination recommended is less than 0.8 footcandle. On streets carrying a heavy traffic volume and where 1.0 footcandle or more is recommended, visibility is more apt to depend on discernment by surface detail, and corrections for pavement reflectance become less important
4. Intersections require illumination in excess of above recommendations.
5. All lighting systems are subject to some depreciation in light delivered to the pavement caused by dirt accumulation on luminaires and the normal aging of the light source. The rate and amount of depreciation will vary with local conditions and it is important that an adequate maintenance program be carried out systematically to minimize such light loss. Such a program should provide for operation of light sources at rated current or voltage, the regular replacement of burned out or depreciated lamps, and the periodic cleaning of luminaires. Where operating conditions are such that a reasonable maintenance program cannot effectively maintain the desired pavement illumination because of the excessive smoke or dirt, corrosive vapor, or other conditions, it is recommended that the initial footcandle level for which the system is designed be increased by an amount sufficient to compensate for the light loss as determined by the local situation.

Table 13-5. Recommended Average Illumination for Highways

LOCATION	ILLUMINATION (footcandles)
Highways	0.3
Intersections, circles, and cloverleaves	0.4

1. The above values are minimum average values on the paved roadway. The illumination at any point should not be less than one-fourth of the above value.
2. These recommendations are based on concrete pavements having a reflectance of the order of 20 per cent. Where the reflectance is less than 20 per cent, the illumination should be increased approximately as follows:

Reflectance 10 per cent: Increase illumination by 50 per cent.

Reflectance 5 per cent: Increase illumination by 100 per cent.

3. At traffic circles and cloverleaves, the areas of convergent and divergent traffic require greater illumination as construction and traffic volume indicate.
4. Regular and systematic maintenance is necessary to maintain the highway lighting system as near to the recommended footcandle value as possible.

Luminaire Characteristics and Application

The choice of the light distribution of a luminaire is determined by mounting height, spacing, and transverse location. Good practice requires that most of the light emitted from a luminaire be directed toward the street and be distributed to ensure good utilization and to provide the recommended average minimum illumination shown in Tables 13-4 and 13-5. Some light should be directed back of the curb line to provide illumination on the sidewalk and adjacent areas.

There is a trend in street and highway lighting practice toward the use of the pendent type of luminaire. It is more efficient than the post-top type and costs less to maintain. The pendent-type luminaire usually is mounted over the roadway, thereby increasing its effectiveness. A pendent-type luminaire and the candlepower distribution in the vertical plane characteristic of typical street and highway equipment are shown in Fig. 13-28. This is the type of vertical light distribution which generally is recommended today. Distributions of this character have maximum candlepower and maximum light flux between the angles of 10 degrees and 20 degrees below the horizontal.

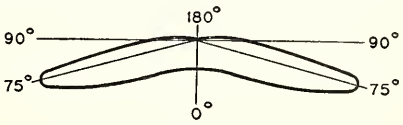


FIG. 13-28. Vertical plane candlepower distribution curve for typical street and highway luminaires.

The five typical candlepower distribution types described in the following paragraphs meet most street and highway lighting requirements. Figure 13-29 shows these distributions in the 75-degree cone. The angles used in the figure follow the usual convention of designating the direction across the street as zero degree, parallel with the street as 90 degrees, and directly back from the street as 180 degrees. Lateral width is the angle at one-half of the maximum candlepower in the cone of maximum candlepower, measured from the luminaire's axis parallel to the curb line and in the direction of the roadway.

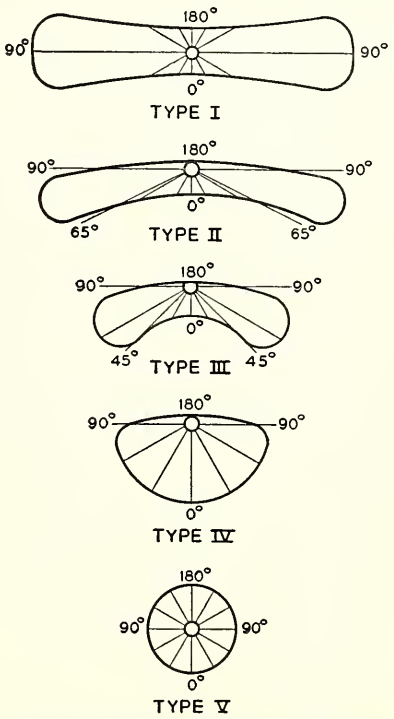


FIG. 13-29. Seventy-five-degree cone candlepower distribution curves for standard types of street and highway luminaires.

Type I luminaire: Two-way dis-

tribution. Intended for mounting approximately over the center of a street. It projects two beams of light in opposite directions along the street, their axis being parallel with the curb line.

Type II luminaire: narrow asymmetric distribution. Intended for mounting at or near the side of a street. It has a narrow distribution, having a lateral width up to 25 degrees in the cone of maximum candlepower at approximately 75 degrees.

Type III luminaire: medium width asymmetric distribution. Intended for mounting at or near the side of the street, has a lateral width up to 45 degrees in the cone of maximum candlepower at approximately 75 degrees. It is intended for wide streets.

Type IV luminaire: wide asymmetric distribution. Still wider laterally than type III. The width is approximately 90 degrees in the cone of maximum candlepower at approximately 75 degrees.

Type V luminaire: symmetric distribution. Candlepower in the 75-degree cone is the same throughout 360 degrees. It is useful where lighting must be installed in center parkways and to some extent for intersections.

Mounting height of luminaires. The recommended mounting heights for luminaires having the distribution characteristics described above are given in Table 13-6. Where practicable, higher mounting may often be preferable.

Table 13-6. Recommended Mounting Heights for Typical Street and Highway Luminaires

LAMP OUTPUT (lumens)	MOUNTING HEIGHT (feet) OF LUMINAIRE TYPE			
	I	II	III	IV and V
2,500	25	20	20	20
4,000	25	25	25	25
6,000	25	25	25	25
10,000	—	30	30	25
15,000	—	—	30	30

Color of Light

Researches have shown that in general the visibility of objects on or near the roadway is substantially the same throughout even the wide differences in color of light from sodium-vapor, mercury-vapor, and filament lamps, when the comparison is on the basis of equal light output and similar distribution.

Design Considerations

In the preparation of recommendations for street and highway lighting all of the following important factors applicable to the specific problem should be carefully evaluated:

1. Traffic density (vehicular and pedestrian).
2. Accident experience.
3. Type and speed of vehicles.

4. Parking practices.
5. Roadway construction features:
 a. Width of street or number of traffic lanes.
 b. Character of pavement surface.
 c. Grades and curves.
 d. Location and width of curbs, sidewalks, and shoulders.
 e. Width and location of dividing and safety islands or channelizing curbs.
6. Special construction features:
 a. Intersections.
 b. Traffic circles, cloverleaves, and separations.
 c. Bridges, viaducts, underpasses, and overpasses.

Street lighting. Table 13-4 lists the illumination recommended for the various classifications of city streets indicated in Table 13-3.

The determination of the light distribution, lamp size, spacing, and arrangement of luminaires required to provide the recommended illumination for any street-lighting project may be made with accuracy and convenience by the methods described in Section 8. Light distribution curves (Fig. 13-29), isolux curves (Fig. 8-20), and utilization curves (Fig. 13-30) for any given luminaire are helpful in designing a street-lighting system to obtain a particular quantity and quality of illumination. Table 13-7 gives typical lighting arrangements for various footcandle levels for several street widths.

All of the light-distribution types referred to in Table 13-8 are most effective when suspended over the street pavement by suitable brackets, mast arms, or other means.

Several photographs of typical installations are shown in Fig. 13-31.

Highway Lighting. The character of traffic on highways differs from that which prevails on urban streets in three particulars that are important from the standpoint of lighting design, namely (1) high vehicular speed (2) less pedestrian traffic, and (3) well-defined traffic lanes. (See Fig. 13-33.)

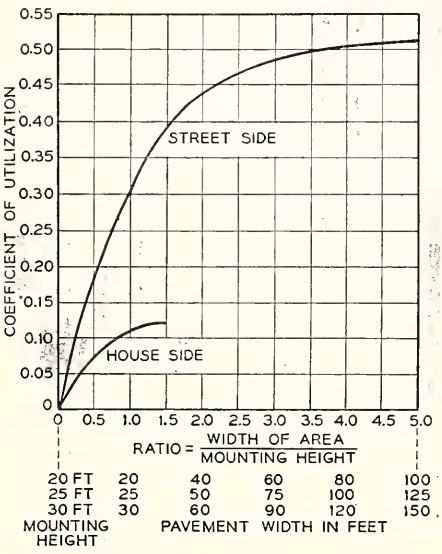


FIG. 13-30. Utilization curves for a street and highway luminaire (type II distribution), showing per cent of total lumen output falling on the pavement on the street and the house sides of the vertical axis. Spacing is measured along the center line of the pavement.

$$\text{Average illumination (footcandles)} = \frac{\text{lamp lumens}^* \times \text{coefficient of utilization}}{\text{spacing} \times \text{width of paved area}}$$

* When luminaires are opposite each other, double lamp lumens value.

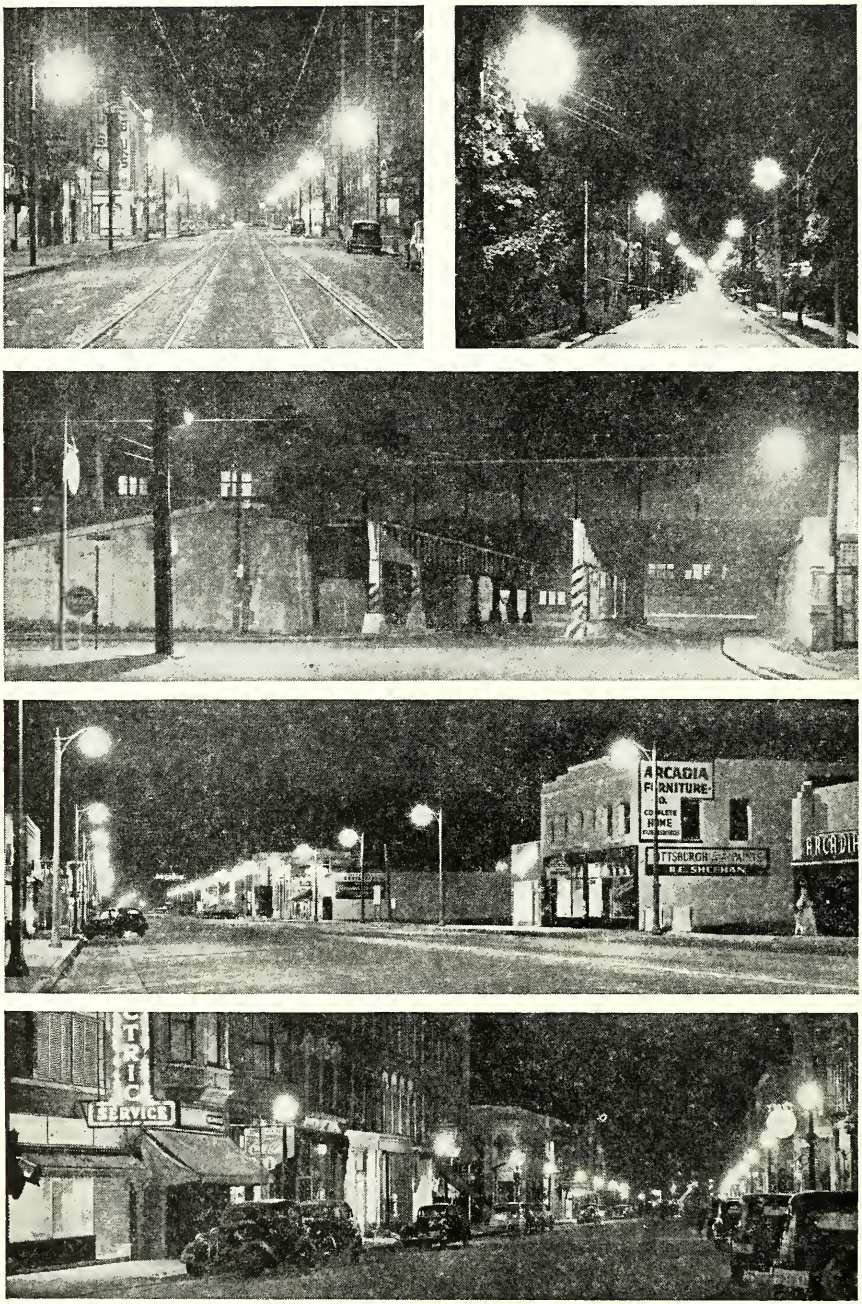


FIG. 13-31. Typical street-lighting installations.

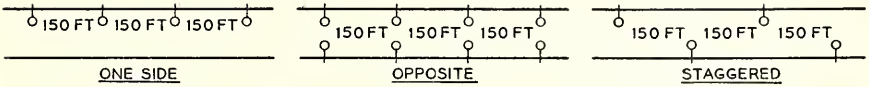


FIG. 13-32. Standard nomenclature for street and highway luminaire arrangement. Specific value of spacing should be substituted for the 150 feet used in the example.

Table 13-7. Typical Arrangement of Luminaires for Urban Streets, with Mounting Height and Spacing for Various Initial Footcandles Values

FOOT-CANDLES	STREET WIDTH	LAMP LUMENS	TYPE DISTRIBUTION	LUMINAIRE* ARRANGEMENT	MOUNTING HEIGHT	APPROXIMATE SPACING
0.2	30	2,500	I	Center	25	170
	40	4,000	II	Staggered	25	200
0.4	40	6,000	II	Staggered	25	155
	50	6,000	IV	Staggered	25	110
0.6	50	10,000	III	Staggered	30	140
	60	10,000	IV	Staggered	25	115
0.8	50	10,000	III	Staggered	30	105
	60	10,000	IV	Staggered	25	85
	70	10,000	III	Staggered	30	85
1.0	50	6,000	II	Staggered	25	55
	60	10,000	III	Staggered	30	75
	80	10,000	IV	Opposite	25	110
1.2	70	15,000	IV	Opposite	30	130
1.6	80	15,000	IV	Opposite	30	90
2.0	80	15,000	IV	Opposite	30	70

* Fig. 13-32 explains the standard nomenclature.

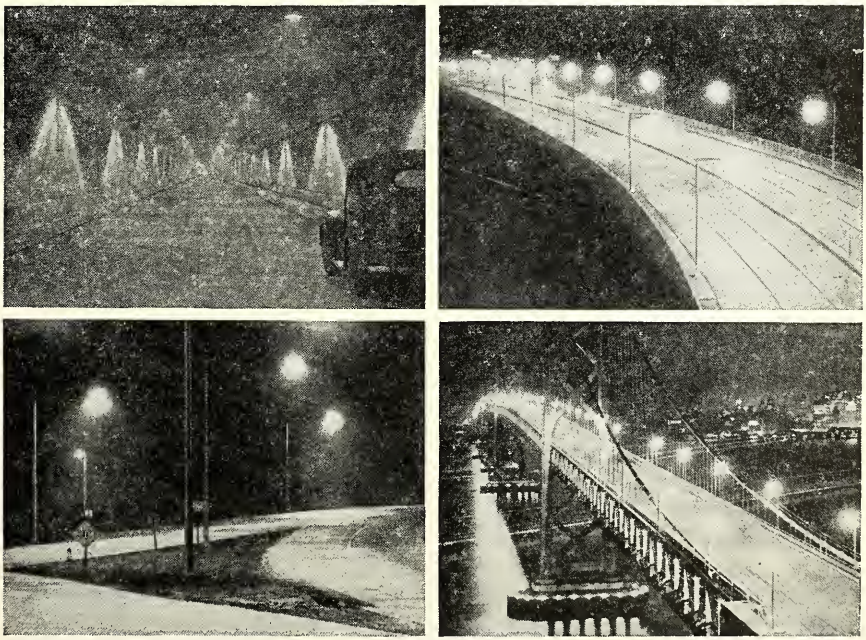


FIG. 13-33. Typical highway-lighting installations.

Table 13-8. Typical Placement of Luminaires for Highway Lighting*

(Average illumination 0.3 footcandle)

LAMP LUMENS	TRAFFIC LANES	PAVEMENT WIDTH (feet)	STAGGERED LUMINAIRE SPACING (feet)	MAST ARM LENGTH‡	
				Pavement with Curb (feet)	10-foot Shoulder (feet)
UNDIVIDED HIGHWAYS					
2,500	2	24	100	4	14
4,000	2	24	165	4	14
4,000	3	36	140	6	16
6,000	4	48	190	10	
6,000	4	48	185		16
6,000	5	60	170	16	
6,000	5	60	160		16
6,000	6	72	150	16	
6,000	6	72	140		16
DIVIDED (DUAL) HIGHWAYS†					
6,000	4-Dual	2-24 5-foot island	175	12	
	4-Dual	2-24 5-foot island	175		16
6,000	4-Dual	2-24 10-foot island	170	16	
	4-Dual	2-24 10-foot island	165		16
6,000	4-Dual	2-24 15-foot island	160	16	
	4-Dual	2-24 15-foot island	155		16
6,000	4-Dual	2-24 20-foot island	150	16	
	4-Dual	2-24 20-foot island	145		16
6,000	6-Dual	2-36 5-foot island	140	16	
	6-Dual	2-36 5-foot island	135		16
6,000	6-Dual	2-36 10-foot island	130	16	
	6-Dual	2-36 10-foot island	125		16

* All luminaires are of type II distribution and mounted at 25 feet.
† Four-lane dual highways with center islands exceeding 20 feet in width and six-lane dual highways with center islands exceeding 10 feet in width to be treated as two separate highways.
‡ It is assumed that poles or standards are located 2 feet back of curbing or 2 feet back of edge of shoulder where there is no curbing.

Situations Requiring Special Consideration

Forestation. The presence of low overhanging foliage or shrubbery may seriously obstruct light projected toward the pavement. Judicious trimming can reduce or eliminate this screening effect. It should be noted that even with high mounted luminaires, it is not necessary to trim all trees to the height of the luminaire. It is necessary to trim only those branches that fall below the cone of maximum candlepower. Such trimming is not noticed when the street is viewed as a vista.

Where trimming is not practicable, a modification of the design may be necessary. For example, luminaires may be mounted on longer mast arms or on span wire suspension over the center of the street, or, as a last

resort, the mounting height may be reduced. Under this last condition luminaires having maximum candlepower at angles less than 75 degrees should be used with reduction in spacing, and perhaps with proportionate reduction in lamp size.

*Protection for pedestrians.** Poor visibility renders the hours of dusk and darkness dangerous for persons walking. The pedestrian accident problem is particularly acute at night where the volume of pedestrian traffic is large or streets are unusually wide and in areas where the population is most dense and children must play in the streets for lack of other playgrounds. Other potentially dangerous areas will be found wherever pedestrians congregate, as on streets around churches, schools, theaters, factories, and street transportation loading zones.

The average footcandle values shown in Table 13-4 for various classifications of streets are the minimum levels of illumination recommended for traffic safety. Experience has shown in many instances that higher illumination values afford increased pedestrian safety. In general, at locations of high accident experience, illumination is recommended which will ensure good visibility.

Curves in roadways. On curving roadways luminaires provide best visibility when located on the outside of the curve. When located on the inside of the curve they are less effective, particularly if the curve is of short radius. (See Fig. 13-34.)

Intersections. Because of the complexity of vehicular and pedestrian traffic at intersections, more illumination is required at such locations. For the average rectangular or diagonal intersection on urban streets the illumination should be at least equal to the sum of the illumination values recommended for the two streets that form the intersection. In all cases, the luminaires should be located to illuminate pedestrian crosswalks. (See Fig. 13-34.)

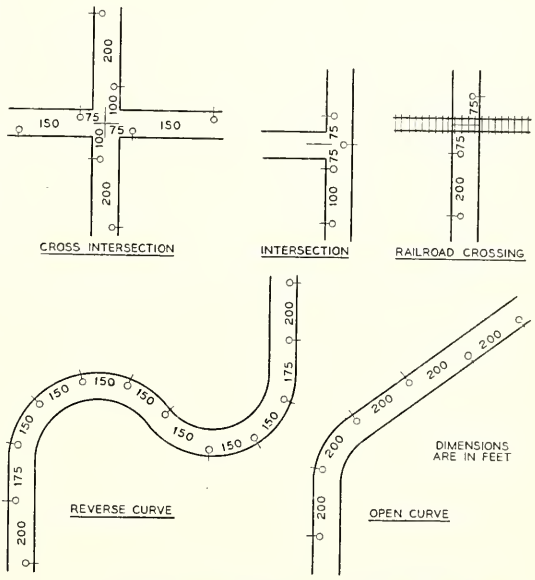


FIG. 13-34. Special street and highway luminaire arrangements recommended for specific hazardous locations.

* The Committee on Pedestrian Control and Protection of the National Safety Council is authority for the statement: "The fatal traffic accident rate per mile of travel is about three times as high during the hours of darkness as during the day. A large percentage of this increased night rate involves pedestrians who are at a particular disadvantage under night-time conditions."—(*Safe on Foot*)

Railroad grade crossings. Railroad grade crossings should be well lighted. If the street or highway is not lighted, two luminaires utilizing not less than 2,500 lumen lamps are recommended for the crossing. (See Fig. 13-34.)

Alleys. Alleys should be lighted so as to permit safe passage and facilitate police protection.

Bridges, overpasses, and viaducts. The level of illumination for such structures should not be less than that recommended for streets or highways carrying an equivalent amount of traffic. When pedestrian walkways are so located that they cannot be lighted by the roadway luminaires, additional lighting for safety and policing should be provided.

Underpasses and tunnels. When an underpass or a tunnel is short, adequate illumination may be obtained from adjacent street-lighting luminaires on the approaches. However, long underpasses and tunnels require special treatment, since electrical illumination may be needed both day and night. In general, the illumination should be approximately 50 per cent greater than that recommended for the connecting street or highway or for a roadway carrying the same volume of traffic.

Vehicular tunnels often utilize design features not common to streets and highways to overcome special problems. The availability of ceiling and walls is an important consideration. For this reason, lighting by the conventional street-lighting methods and equipment may not be the most satisfactory obtainable.

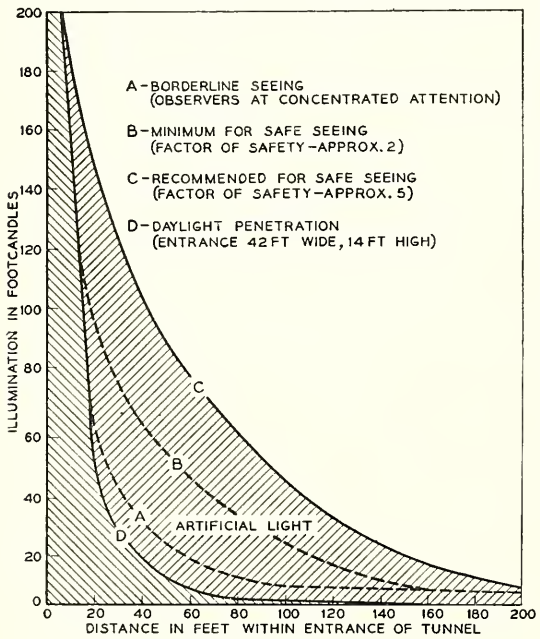


Fig. 13-35. Daytime tunnel-entrance illumination conditions evaluated with respect to 35-miles-per-hour driving speed.

Daytime tunnel entrance electrical illumination should be planned so that drivers may become adapted gradually to the lower tunnel levels of illumination as they enter and to the higher daylight levels as they leave. A graduation in level by which this may be accomplished for a driving speed of 35 miles per hour is shown in Fig. 13-35.

FIELD LIGHTING FOR AIRPORTS

Field-lighting equipment for airports generally is classed as signal equipment. With the exception of landing area and loading area floodlights, and illuminated wind cones or socks, airport lights convey the information intended by means of their own color, arrangement, or direction, rather than by illumination of other areas or objects. The amount of light normally required for this purpose is not large, but the control of its direction and color must conform with rigid standards.

Since the signal equipment must serve its purpose under varying atmospheric conditions, a control of the brightness of the runway and the approach lights used for landing the airplane must be provided. Low brightnesses are used in clear weather, and are increased as the transmittance of the atmosphere decreases. For practical purposes, the useful range of the signal remains the same over a rather wide variance of atmospheric conditions.

Standardization

The interstate and international scope of scheduled air transport operations makes it imperative to set up minimum performance standards for apparatus and to standardize colors and characteristics of signals.

The Civil Aeronautics Administration (C.A.A.) of the Department of Commerce is the domestic agent for the establishment of such standards and recommendations in civil aviation. In many cases the Army, the Navy, and the C.A.A. have collaborated in reaching joint standards, known as A.N.C. Aeronautical Standards.

International practices and standards are formulated by the U. N. sponsored International Civil Aviation Organization (I.C.A.O.), which is composed of representatives of all nations interested in international air commerce. Standards adopted by this body generally are accepted by all member nations and made mandatory minimum requirements.

Seeing Problems, Incoming Aircraft

In many landing fields all of the recommended types of lights and luminaires are not always necessary, but there should be uniformity in those used for the very evident advantage it gives the pilot, who thus can be familiar with the meaning of the lighting at any airport.

The seeing problems for pilots of incoming aircraft include:

1. Locating the airport.
2. Determining the usable landing area.
3. Determining the wind direction.
4. Determining the landing direction.
5. Locating the obstructions.
6. Utilizing perception of depth and of rate of change of depth to determine altitude.
7. Determining taxiing direction.
8. Establishing visual contact from an instrument approach.

The equipment used and the methods of solving these seeing problems are as follows:

1. The airport location is marked by an *airport beacon* (as in Fig. 13-36), designed to give a definite periodic sequence of flashes which will be visible to the pilot from any normal angle of approach. The standard land airport signal consists of six white and six green alternate flashes per minute. Each flash should have a minimum duration of 0.15 second when clearly visible.

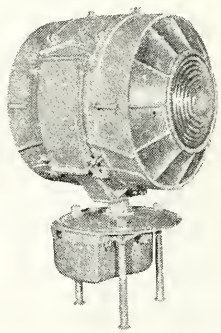


FIG. 13-36. Typical air port beacon which indicates location by six white and six green alternate flashes per minute with clearly visible duration of at least 0.15 second.

2. *Boundary lights* are used to outline the entire usable landing area of an all-way airport. *Strip lights* are used when the area available for landing is a single strip. *Runway lights* are used when most landings are restricted to paved runways. (See Fig. 13-37.)

Boundary lights are fixed white lights, with a symmetrical horizontal distribution and an asymmetric vertical distribution. Strip lights are fixed white lights, and may have the same distribution as boundary lights, or they may have an asymmetric distribution in both horizontal and vertical planes, with maximum candlepower parallel to the strip axis.

Runway lights have an asymmetric distribution in both horizontal and vertical planes, with a maximum candlepower approximately parallel to the axis of the runway. Runway lights are fixed white lights for all except those on the last 1,500 feet of the runway, which are yellow. This is accomplished for either direction of approach by using split filters to show yellow in one direction only on the units 1,500 feet in from each end of the runway.

Runway lights may be either semiflush or elevated. Elevated lights include *day markers*, usually a small painted cone mounted directly under the light.

High-intensity runway lights are high candlepower elevated lights, physically large enough to serve as day markers without the use of auxiliary cones. The candlepower of a high-intensity runway light is many times that of a semiflush or elevated runway light.

3. Wind direction is indicated visually by an *illuminated wind cone*, *wind tee*, or *wind tetrahedron*. A wind cone is a large cloth cone, or "sock," free to swing around a vertical shaft and illuminated from above by lamps and reflectors. A wind tee consists of a large free-swinging, T-shaped wind vane with its shape clearly outlined by rows of lamps. A wind tetrahedron is a large triangular pyramid turned on its side, free swinging, and with all edges outlined by rows of lamps. (See Fig. 13-38.)

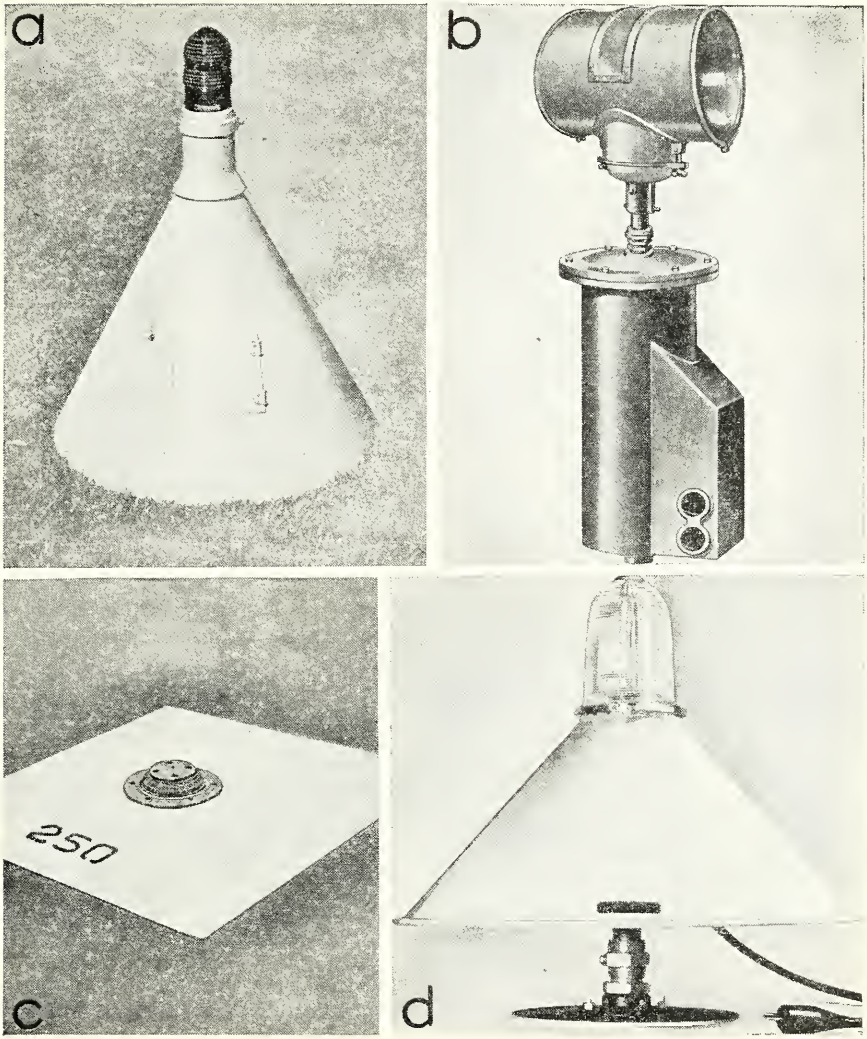


FIG. 13-37. Typical lights used to mark usable landing areas: (a) boundary or strip light; runway lights (b, high-intensity, c, semiflush, d, elevated).

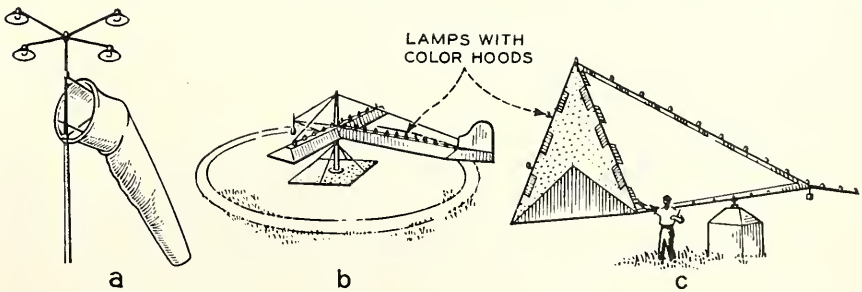


FIG. 13-38. Typical illuminated wind-direction indicators: (a) cone, (b) tee, (c) tetrahedron.

4. Landing direction is determined visually:
 a. On an all-way field by *range lights* inserted in the boundary circuit, indicating preferred landing directions. Range lights are fixed green boundary lights installed across each end of preferred landing paths to indicate landing direction. The landing paths are coded by using two, three, or more lights across each end of the same preferred path. (See Fig. 13-39.)
 b. On a landing strip by the outline of the strip as indicated by the strip lights and by green threshold lights.
 c. On a runway by the runway outline indicated by runway lights and by green threshold lights.

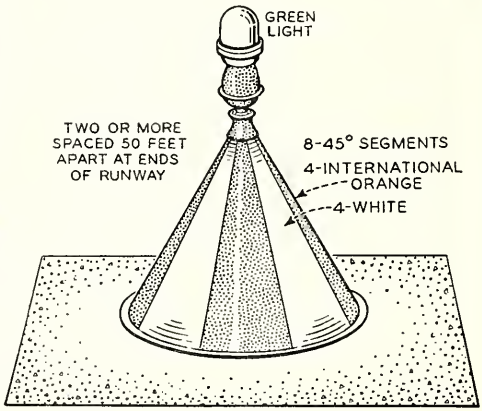


FIG. 13-39. Typical range-light.

5. Obstructions are identified by fixed, flashing, or rotating red lights. All structures or objects that constitute a hazard to aircraft landing or taking off are marked by red lights having an asymmetric vertical distribution and a symmetric horizontal distribution. (See Fig. 13-40.)

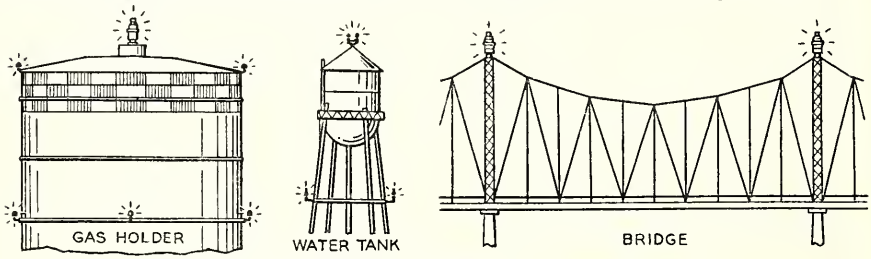


FIG. 13-40. Typical obstruction-light installations.

6. Depth perception is aided by the pattern appearance of the boundary, strip, or runway lights, and by their altitude relative to obstruction lights.
7. Taxiing direction is determined after landing:
 a. On an all-way field by utilizing the landing lights on the aircraft, ground-mounted floodlights to identify the loading area, or a tower-controlled searchlight which can throw a moving spot or light to guide the aircraft, or by any combination of these.
 b. On a landing strip by following the strip lights to a lighted loading area.
 c. On a runway field by following *taxiway guidance lights.* These are blue lights (either semiflush or elevated), having an asymmetric vertical distribution, and either a symmetric or an asymmetric horizontal distribution, arranged to outline the taxiway.

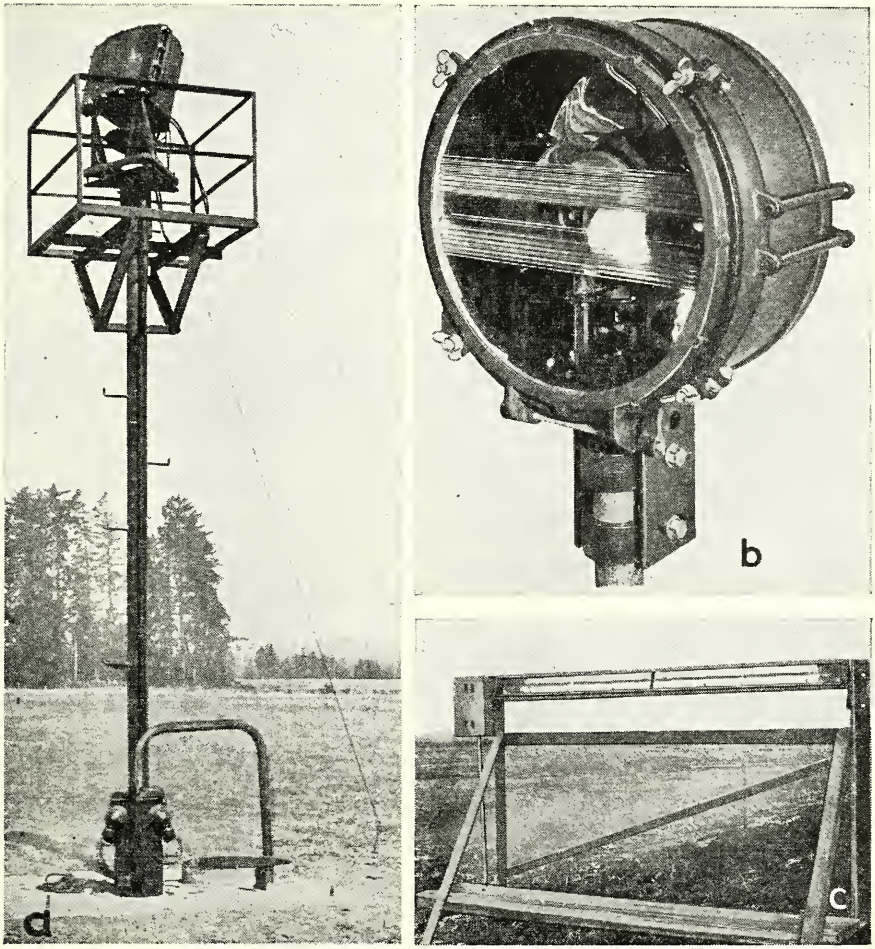


FIG. 13-41. Three types of approach lights used to establish visual contact after an instrument approach: (a) red incandescent type, (b) projector type, (c) neon ladder type.

8. The seeing problem involved in establishing visual contact from an instrument approach can occur only at airports where instrument-approach equipment is installed.

Three methods of solving this problem are in use, the choice depending on the funds available. (See Fig. 13-41.) These methods are:

a. The *neon-lamp-ladder approach system*, comprising a row of red neon tubes in linear parabolic reflectors (spaced 100 feet apart, 85 feet left of the extended center line of the runway), operated as fixed lights at a single intensity.
b. The *incandescent-lamp approach system*, comprising two rows of red incandescent lamp luminaires with vertical and horizontal

asymmetric distribution, spaced 200 feet apart in rows (each row in line with the respective row of runway lights), operated as fixed lights at any one of five selected intensities.

c. The *projector approach system*, comprising two rows of high-candlepower, red searchlight-type luminaires with asymmetric vertical and horizontal distribution, spaced 200 feet apart in rows (each row on a line parallel to the respective row of runway lights), operated as fixed lights at any one of five selected intensities.

Seeing Problems, Outgoing Aircraft

The seeing problems for pilots of outgoing aircraft include:

1. Determining the wind direction.
2. Determining the take-off direction.
3. Determining taxiing directions.
4. Determining the usable take-off area.
5. Locating obstructions.
6. Utilizing perception of depth and of rate of change of depth to determine altitude.
7. Determining the horizon.

The equipment used, and the methods of solving these seeing problems, are as follows:

1. Wind direction is indicated visually by the illuminated wind cone, tee, or tetrahedron described on page 13-44.
2. The take-off direction is determined visually:
 a. On an all-way field by lining up the coded range lights in the boundary circuit corresponding to the wind direction.
 b. On a landing strip or runway field by the strip lights or runway lights and by green threshold lights.
3. The taxiing direction is determined visually:
 a. On an all-way field by the boundary light pattern, by a tower-controlled searchlight which can throw a moving spot of light to guide the aircraft, by the landing lights on the aircraft, or by any combination of these.
 b. On a landing strip by following the strip lights to the take-off end of the strip.
 c. On a runway field by following taxi-way guidance lights.
4. The usable take-off area is determined visually:
 a. On an all-way field by the distance between the selected range lights.
 b. On a landing strip or a runway field by the length and width of the lighted strip or runway.
5. Obstructions are located by the obstruction lights mounted on structures or objects that constitute hazards to the take-off.
6. Depth perception is aided on take-off by utilizing the range and boundary lights, the strip lights or the runway lights, as a reference until they pass below the ascending aircraft.

7. The horizon is determined visually by the range and boundary lights, the strip lights, or the runway lights during the take-off run. Other lights, such as street lights, or the lights in dwellings, railroad yards, or industrial plants, serve to establish the horizon when air-borne. In locations where the take-off is over an area devoid of such lights, *horizon lights*, consisting of boundary light fixtures operated as steady burning white lights, are provided. At least two lights not less than 1,000 feet apart across the take-off path, are located from 1 to 3 miles from the boundary and substantially equidistant either side of the take-off path.

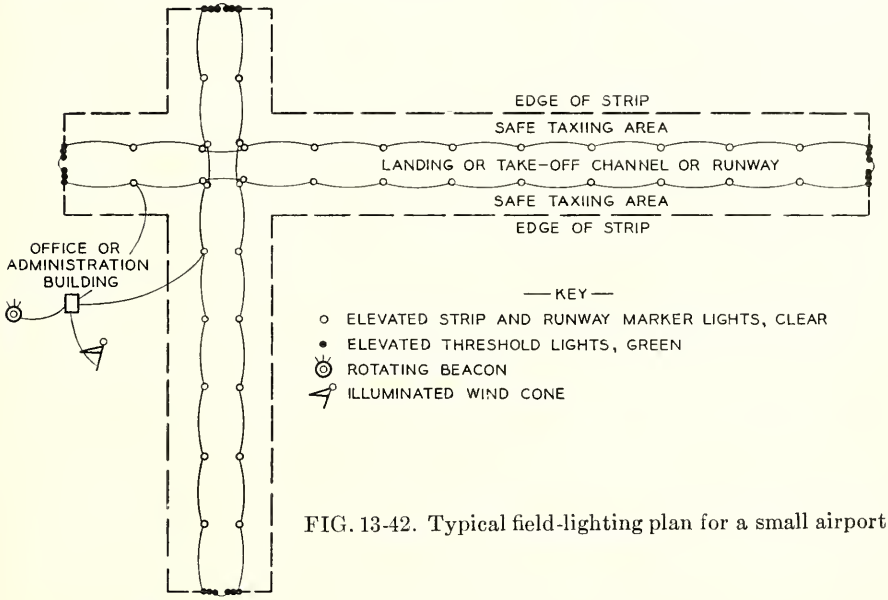


FIG. 13-42. Typical field-lighting plan for a small airport.

Airport Classification

Airports are divided into classes I, II, III, IV, and V, the basis being useful runway length. The class required for a given locality is governed by the types and the number of planes which will make use of the airport, determining factors being wing loading and power loading. The useful runway lengths for the five classes are:

AIRPORT CLASSIFICATION	LANDING STRIP LENGTH
I	1,800 to 2,700 feet
II	2,700 to 3,700 feet
III	3,700 to 4,700 feet
IV	4,700 to 5,700 feet
V	5,700 feet and over

For each class of airport, certain other limiting design standards apply, among which are runway and taxiway widths, distances from runways and taxiways to aprons and buildings, grades, approach path ratios for obstruction clearance, runway paving loads, and field lighting facilities. (See Fig. 13-42.)

Table 13-9 lists the minimum lighting facilities recommended for each class of airport. These recommendations are subject to variation to suit local conditions which may require less elaborate or more extensive treatment.

Table 13-10 gives reference data on airport lighting equipment.

Table 13-9. Airport Lighting Standards

MINIMUM RECOMMENDED FACILITIES	AIRPORT CLASS				
	I	II	III	IV	V
Airport beacon	x	x	x	x	x
Identification (code) beacon*	x	x	x	x	x
Boundary and range lights†	x	x	x	x	x
Obstruction lights	x	x	x	x	x
Illuminated wind cone	x	x	x	x	x
Runway and threshold lights		x	x	x	x
Illuminated wind tee or tetrahedron			x	x	x
Apron floodlights			x	x	x
Ceiling projector and clinometer			x	x	x
Taxiway guidance lights				x	x
Approach lights‡				x	x

* The identification beacon is required only when there is another lighted airport near by.
† Boundary lights should be omitted on runway-type fields.
‡ Approach lights should be installed for each instrument-landing runway.

Table 13-10. Reference Data on Airport Lighting Equipment

TYPE OF EQUIPMENT AND USE	LOCATION	TYPE OF LAMP (Incandescent Filament)	COLOR INDICATION	MOUNTING	SPACING
Airport beacon Used to denote airport location	On or adjacent to airport	500-Watt*, 30- or 115-volt, T-20 bulb, medium bipost base; 1,000-watt, 30- or 115-volt, T-20 bulb, mogul bipost base; or 1,500-watt,† 32-volt, T-24 bulb, mogul bipost base	Alternate white and green flashes	Sufficient height for beam to clear surrounding obstructions. Usually on top of control tower, building, or other structures, at least 50 ft high	
Identification beacon Used to identify positively a particular point on earth's surface	Usually above or immediately adjacent to airport beacon	500-Watt, 115-volt, PS-40 bulb, mogul prefocus base	Green flashes in Morse code	Usually mounted above airport beacon on auxiliary platform where the beam will clear all surrounding obstructions	
Approach light (high intensity). Used to indicate desired line of approach to a landing area	On approach area as extensions of runway lights for distance of approximately 2,000–3,000 ft	200-Watt, 6.6-ampere, PS-30 bulb, mogul prefocus base; 250-watt, 20-ampere, T-10 bulb, medium prefocus base; or 500-watt, 115-volt, T-20 bulb, medium prefocus base	Red	On low base at ground, or on poles to establish level grade from runway end or rising curve	200 ft

Table 13-10 (Continued)

TYPE OF EQUIPMENT AND USE	LOCATION	TYPE OF LAMP (Incandescent Filament)	COLOR INDICATION	MOUNTING	SPACING
Runway light (high intensity). Used on all instrument runways to indicate limits of area available for landing and take-off.	10 ft outside runway edge parallel to the runway, opposite each other and so circuited that a single runway may be delineated as a unit	200-Watt, 6.6-ampere, PS-30 bulb, mogul prefocus base; 250-watt, 20-ampere, T-10 bulb, medium prefocus base; or 500-watt, 115-volt, T-20 bulb, medium prefocus base	White on full length of runway except one-half white and one-half yellow within 1,500 ft of each end of runway	Mounted on ground or on a low base with breakable joint which will give way if light is struck accidentally by an airplane. Maximum extension 30 in. above surface	200 ft
Threshold light (high intensity) Used in conjunction with and in same circuit as high-intensity runway light to indicate usable limits of runway	Across each end of runway along line perpendicular to runway center line, symmetrically spaced in two groups, one group on each side of runway, leaving an 80-ft clearance gap at runway center‡	200-Watt, 6.6-ampere PS-30 bulb, mogul prefocus base; 250-watt, 20-ampere, T-10 bulb, medium prefocus base; or 500-watt, 115-volt, T-20 bulb, medium prefocus base	Green	Mounted on ground or on a low base with a breakable joint which will give way if light is accidentally struck by an airplane. Maximum extension 30 in. above surface	(See location)
Runway light (low intensity). Used on runways to indicate area available for landing and take-off.	Along both edges of runway paving, opposite each other and so circuited that a single runway may be delineated as a unit	40-Watt, 115-volt, A-21 bulb, medium prefocus base; or 325-lumen, 6.6-ampere, A-21 bulb, medium prefocus base.	White on full length of runway except one-half white and one-half yellow within 1,500 ft of each end of runway	Mounted semi-flush with pavement, heavy prismatic glass and steel cover. Maximum extension 4 in. above surface	200 ft
Threshold light (low intensity) Used in conjunction with and in same circuit as low-intensity runway light to indicate usable limits of runway	Across each end of runway along a line perpendicular to runway center line and at uniformly spaced intervals of 50 ft. On runways less than 150 ft wide spacing should be decreased to allow a total of four to be used	100-Watt, 115-volt, A-21 bulb, medium prefocus base; or 1,020-lumen, 6.6-ampere, A-21 bulb, mediumprefocus base	Green	Mounted semi-flush with pavement, heavy prismatic glass and steel cover. Maximum extension 4 in. above surface	(See location)
Boundary light Used to outline limits of landing area	Around boundary of landing area and so circuited that entire landing area is delineated as a unit	40-Watt, 115-volt, A-21 bulb, medium prefocus base; or 325-lumen, 6.6-ampere, A-21 bulb, medium prefocus base	White	Normally on boundary cones	300 ft
Range light Used on an all-way field to indicate a preferred landing path	Across each end of preferred landing path in boundary light circuits	100-Watt, 115-volt, A-21 bulb, medium prefocus base; or 1,020-lumen, 6.6-ampere, A-21 bulb, medium prefocus base	Green	Normally on cones. Landing paths are coded by using two, three, or more lights across each end of same preferred landing path§	50 ft Apart

Table 13-10 (Continued)

TYPE OF EQUIPMENT AND USE	LOCATION	TYPE OF LAMP (Incandescent Filament)	COLOR INDICATION	MOUNTING	SPACING
Obstruction light Used to indicate obstructions or potential hazards to aircraft	On obstructions: (*a*) 150 ft or more above landing area and within 2 miles, (*b*) within approach or take-off areas and extending above a plane of 1:40 inclination, or (*c*) within transitional areas and extending above a plane of 1:7 inclination	100 Watt, 115-volt, A-21 bulb, medium prefocus base; 111-watt, traffic signal, 115-volt, A-21 bulb, medium screw base; or 1,020-lumen, 6.6-ampere, A-21 bulb, medium prefocus base	Red	At top for heights to 150 ft, with additional light for each 150 ft, or fraction thereof, equally spaced. Additional lights will be equally spaced between top light and ground level	Not over 150 ft horizontal spacing
Taxiway light (low intensity) Used to delineate taxiway Used on Taxiway to indicate path from terminal to point of take-off and from point of landing to terminal.	Along both edges of taxiway. On straight sections, opposite each other. On short sections, curved edges and intersections so positioned that path of taxiway is clearly indicated.	40-Watt, 115-volt, A-21 bulb, medium prefocus base; or 325-lumen, 6.6-ampere, A-21 bulb, medium prefocus base	Blue	Mounted semiflush with pavement, heavy prismatic glass and steel cover. Maximum extension 4 in. above surface‖	200 ft on straight sections.
Taxiway light (elevated) Same as above	Same as above	30 or 45-watt, 6.6-ampere, T-10 bulb, medium prefocus base, or 40-watt, 115-volt, T-10 bulb, medium prefocus base.	Blue	Mounted on ground on low base with a breakable joint which will give way if light is accidentally struck by airplane¶	200 ft on straight sections
Landing area or runway floodlight Used for general illumination of runway or landing area	At end of runway or at edge of landing area	1,500-Watt, 32-volt, T-24 bulb, mogul bipost base; or 3,000-watt, 32-volt, T-32 bulb, mogul bipost base	White	On pipe standards or vaults in banks of two or more units all on one side or on both sides of runway.	
Apron floodlight Used to illuminate surface of apron	As required and so positioned as to avoid light being projected into pilot's eyes during landing or taking off of aircraft and to produce minimum of 0.5 footcandle	General lighting service lamps	White	Usually on airport buildings or on ground on flat base or pipe mountings	
Wind sock Used to indicate true wind direction	On building roof or on ground, where visible from all points and where wind is not influenced by buildings or natural obstacles	General lighting service lamps as required, usually 100-, 150-, or 200-watts	White	Mounted on low friction bearings attached to pipe standard to permit free rotation with the wind, and on hinged pole for ease of relamping	
Wind tee Used to indicate true *ground* wind direction	On ground near, or on edge of, landing areas, where visible from all points and where wind is not influenced by buildings or natural obstacles	25-Watt, 115-volt, A-19 bulb, medium-screw base	Green	Mounted on low friction bearings on vertical shaft to permit free rotation with the wind	Lamps on tee spaced maximum of 1 ft apart

Table 13-10 (Concluded)

TYPE OF EQUIPMENT AND USE	LOCATION	TYPE OF LAMP (Incandescent Filament)	COLOR INDICATION	MOUNTING	SPACING
Tetrahedron Used to indicate direction of landing or take-off where traffic control is exercised. When swinging free indicates true *ground* wind direction	Same as Wind Tee	10-Watt, 115-volt, S-14 bulb, medium-screw base	Red on left side, green on right side, top edge, and tip	Mounted on low friction bearings on vertical shaft for free rotation with wind when not controlled from tower	
Ceiling projector Used to determine cloud strata height	At a known distance from observation point, usually 1,000 ft	420-Watt, 12-volt, G-25 bulb, mogul prefocus base	White	Projector mounted to direct beam upward, usually 90 degrees	
Runway light (elevated) Strip light (elevated) Used on runways and strips to indicate the area available for landing or take-off.	10 ft out from edge of runway paving or strip, parallel to strip or runway, opposite each other and so circuited that a single runway or strip may be delineated as a unit	30- or 45-watt, 6.6-ampere, T-10 bulb, medium prefocus base; or 40-watt, 115-volt, T-10 bulb, medium prefocus base	White on full length of runway or strip, except one-half white and one-half yellow within 1,500 ft of each end of runway	Mounted on ground or on a low base with breakable joint which will give way if light is struck accidentally by an airplane‖	200 ft
Threshold light (elevated) Used in conjunction with and in the same circuit as the elevated strip or runway light to indicate usable limits of runway or strip	Across each end of runway or strip symmetrically spaced in two groups, one group on each side of runway or strip, perpendicular to runway or strip leaving an 80-ft clearance gap at center of runway or strip‡	30- or 45-watt, 6.6-ampere, T-10 bulb medium prefocus base; or 40-watt, 115-volt, T-10 bulb, medium prefocus base	Green	Mounted on ground or on a low base with breakable joint which will give way if light is struck accidentally by an airplane. Maximum extension 30 in. above surface	(see location)

* If a 500-watt lamp is used with a 24-inch beacon, an auxiliary reflector is required.

† Can be used only in special spherical or cylindrical beacon.

‡ Six are used with runway lights not more than 220 feet apart opposite each other, eight are used with runway lights over 220 feet apart opposite each other. With strip lights, only six elevated lights necessary.

§ The landing path prescribed for low wind conditions (less than 5 knots) shall have the greatest number of lights, or, in the absence of such a prescription, the longest landing path shall have the greatest number of lights.

‖ As new installation: lights shall be located 10 feet out from edge of runway paving opposite each other. As replacements: lights shall be mounted on top of flush runway light housings. Maximum extension 30 inches above surface for all installations.

¶ As new installation, lights shall be located 10-feet out from edge of taxiway opposite each other. As replacements, lights shall be mounted on top of flush taxiway light housings. Maximum extension 30" above surface for any installation.

ILLUMINATED RAILROAD SIGNALS

Illuminated signals provide one means whereby railroad operating personnel can "see" conditions affecting traffic and convey messages beyond the range of ordinary unaided vision. The engineer perceives the lighted signal by the same visual attentiveness with which he watches the track.

Functions Performed by Light Signals

The information to be conveyed with the aid of light signals may be considered in two general categories:

1. Instructions covering a forthcoming movement or sequence of moves.
2. Identification and location of trains, switches, and other fixed installations or obstructions.

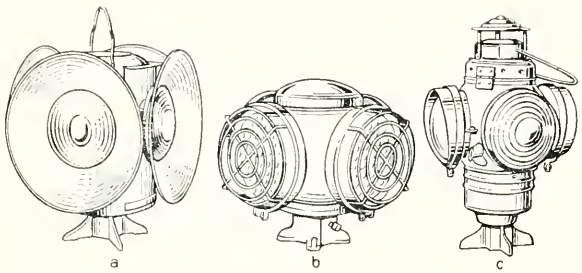


FIG. 13-43. a. Electric switch lamp. b. Reflex switch marker. c. Kerosene switch lamp.

Representative of the function of conveying identification and location information, the switch light, or a reflex device (such as shown in Fig. 13-43), enables the trainman to locate a switch at night, and tells him by its color whether the switch is reversed or normal. A wayside signal locates for him the entrance to a certain territory and its aspect indicates whether the way is clear to proceed. The display of a red light in a signal indicates that a train occupies the next block, or that a switch may be improperly lined, or that a rail may be broken so as to interrupt automatic operation. The appearance of the light is similar to that of the red hand lantern or markers that must be lighted at night on the rear of every train. Two white classification lights, such as shown in Fig. 13-44, displayed on the front of an engine at night identify the train as an extra. Two green lights displayed in the same location are used on all sections of a train except the last, when a scheduled train is operated with more than one section. Lighted marker lamps, such as shown in Fig. 13-44, are used to indicate the rear of a train at night. Blue lanterns commonly serve to mark the location of men working under or about cars or locomotives and warn against moving or coupling such equipment.

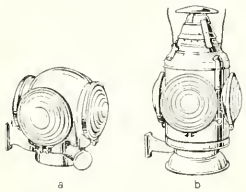


FIG. 13-44. a. Locomotive classification light. b. Kerosene tail-marker lamp.

Wayside Signal Equipment

Wayside signals had their beginnings in nonilluminated mechanical devices, such as the ball suspended from a rope (from which the term "highball," meaning "go ahead," had its origin). The modernized version of the old semaphore signal, has permitted continued use for daytime indication of the long standard nonilluminated blade to which is added a light which can be changed in color in synchronism with the blade position. The kerosene lamps with which the early lighted semaphore signals were equipped were satisfactory for night signals, but not bright enough, however, for daytime color-light indications. In lighted semaphores the change of color is accomplished by mounting colored glass roundels in a spectacle near the fulcrum of the semaphore arm so that different colored glasses swing into position to intercept the white beam projected by the lamp and optical system, with change of position of the semaphore blade.

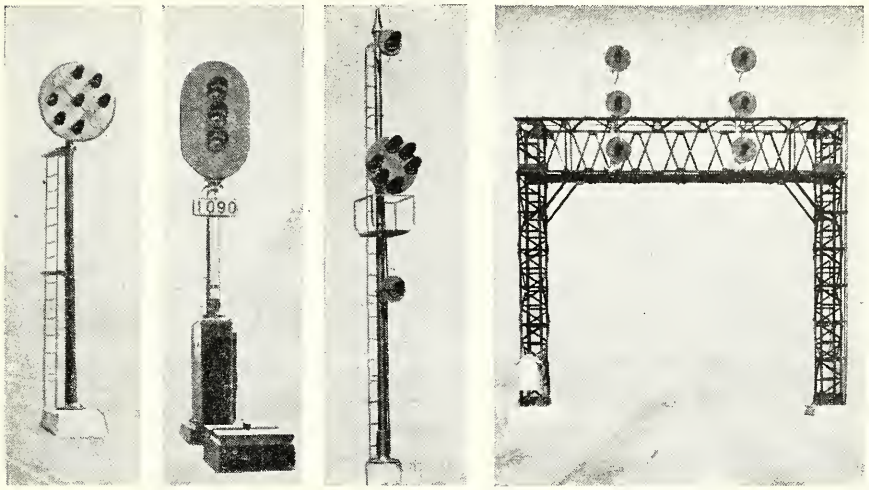


FIG. 13-45. a. Position-light signal. b. Color-light signal. c. Color-position-light signal. d. Searchlight-type of color-light signals.

With increased candlepower available in modern signal units utilizing electric sources and improved lens design, it has become possible to depend upon visibility of the light for both day and night operation. To ensure contrast of the light with its surroundings in the daytime, a black target or background surrounds the light wherever a signal must be viewed at long range. There are three types of signals currently recognized by the Association of American Railroads (A.A.R.) which depend entirely upon lights. These are: color-light signals, position-light signals, and color-position-light signals. (See Fig. 13-45.)

In the *searchlight type* of *color-light signal* the change of color is accomplished by an electrically-controlled mechanism completely enclosed inside the signal unit. The rays from an incandescent filament are collected by an ellipsoidal reflector which focuses them to a small spot. At this spot the rays pass through any one of three, colored, 1-inch diameter glass disks mounted in a delicately balanced, pendulum-like spectacle. An accurate lens system directs the light to cover the angle of approach.

The *position-light signal* is a type of wayside signal which does not depend upon color discrimination by the engineer. In this type, a number of lamps (maximum nine) are mounted on a circular target: eight lights arranged in a circle, one in the center. By operating three lamps at a time, the aspect of the signal may be a vertical row, a horizontal row, or a diagonal. Each of the target lamps is focused by its own projector system in the direction of the approaching train.

The *color-position-light signal* is a type which utilizes a combination of the principles of the color-light and the position-light systems. Here also there are several lights on a target. These may be lighted in pairs: vertical pair (green); horizontal pair (red); right and left diagonal pairs (yellow and lunar white, respectively).

Locomotive Cab Signals

By suitable track circuits and electrical receiving equipment on locomotives, automatic signal lights inside the locomotive cab can be made to show signal aspects corresponding to those of the wayside signals governing the train movement. This is useful in times of poor visibility caused by atmospheric conditions or other obstructions.

Power Sources for Lights

Complete dependability required of wayside signals has made necessary operation on the most reliable independent-power sources possible. Therefore, primary or storage batteries are used most frequently alone, or as standby for a-c service. However, many switch lamps at isolated wayside locations and markers on the rear of trains are operated by kerosene burners.

Oil Burning Signal Lamps and Lanterns

The kerosene burner light source has an intensity of from about 1 to 3 candlepower, depending upon the size of the wick, flame, and draft conditions. When used with a clear $5\frac{3}{8}$ inch diameter by $3\frac{1}{2}$ inch focal length Fresnel (step) lens, such as shown in Fig. 13-46, a kerosene burner produces an axial beam of approximately 60 candlepower. The beam width in this case is established by the width of the flame and may range from about 7 to 20 degrees for various types of burners. Additional spread and lower candlepower is obtained with spreading lenses with vertical fluted patterns on the outside surface.

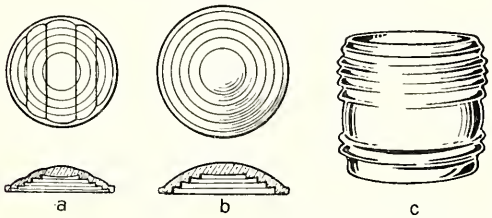


FIG. 13-46. b. Optical-type Fresnel (step) lens. a. Spreading-type lens. c. Fresnel-lens-type, hand-lantern globe.

The Fresnel type of prismatic globe concentrates the light in a horizontal beam with a maximum candlepower approximately seven times that of the same lantern equipped with a plain globe. The vertical beam divergence for the Fresnel is about 6 to 9 degrees.

Oil-burning tail-marker lamps, switch lamps, and semaphore lamps are equipped with lenses. Electric hand lanterns equipped with dry cells are in extensive use where white light is required; however, kerosene lanterns are standard where a colored indication is needed. (See Fig. 13-47.)

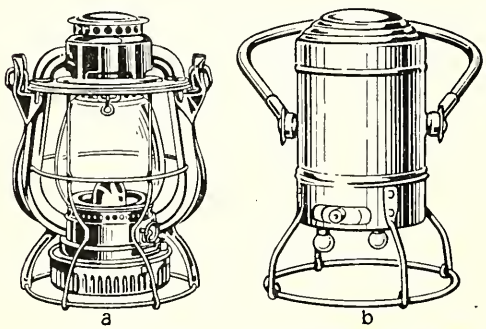


FIG. 13-47. a. Kerosene hand lantern. b. Electric hand lantern.

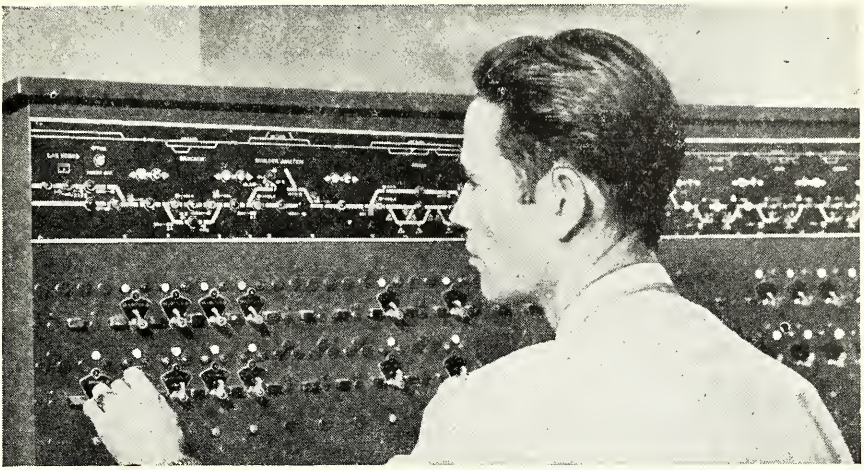


FIG. 13-48. Centralized traffic control panel with illuminated track model and lever lights.

Signal-System Control Panels

In addition to the use of signal lights on trains and along the right of way, there is another important category of light indications in a signal system. These are the indicator lights on the panel from which an operator handles an *interlocking*, or *centralized traffic control, system.* On such a panel the operator has before him levers that operate electrical relays for switches and signals along a portion of the rail line or yard. (See Fig. 13-48.) Associated lever lights indicate the response of switches and signals to the positions of the control levers. Accompanying the levers is a track diagram for the territory involved which is studded with indicator lights that show when a train occupies certain sections of track along the line.

Range of Light Signals

The range of a railroad light signal is determined by its daytime visibility rather than by its night visibility. The formula which is in general use for relating the beam candlepower to the maximum range of a red or green signal is:

Range in feet = $\sqrt{2{,}000}$ bcp

where bcp = beam candlepower of the signal equipped with colorless glass.

Yellow will have somewhat longer range. The formula does not apply to purple or blue.

By use of this formula and the candlepower distribution curve of a signal beam, it is possible to lay out a chart or plan that shows the ground area over which this particular signal will be within visible range. This signal range plan can be superimposed over a track plan to see whether the signal would have visibility over the desired track approach to the

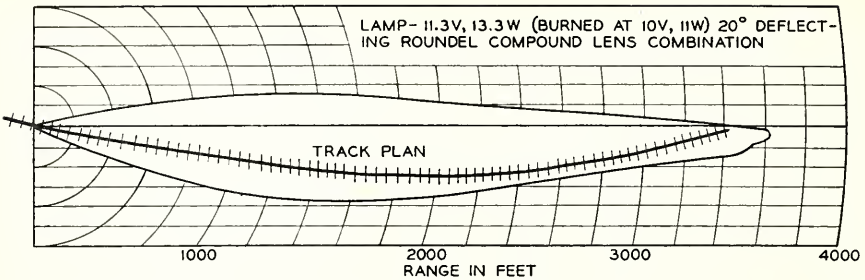


FIG. 13-49. Range chart for searchlight-type signal-unit with part of a track plan superimposed to show range of useful coverage.

signal. For convenience in using this method, signal manufacturing companies have presented range charts on their various signal units with a celluloid transparency on which is ruled a large number of representative track curves which can be laid readily on top of the signal range charts. (See Fig. 13-49.)

Lamps and Relation of Voltage to Beam Candlepower

Table 13-11 gives the 1,000-hour ratings, service ratings, and other information relative to lamps used with searchlight-type color-light signals. The lamps are the precision, two-pin, candelabra-bayonet-base type. The higher wattage lamps produce beams of high candlepower even when burned at the recommended reduced voltage, thereby obtaining average life well in excess of 1,000 hours. The table shows the average axial beam candlepower obtained with lens combinations for each lamp when burned at its recommended voltage.

Light Control and Optical Considerations

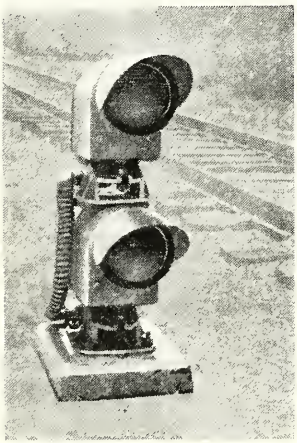


FIG. 13-50. Dwarf searchlight signal unit with upward deflecting roundels.

It is important that signal-unit optical systems be carefully selected and that each signal unit be properly aligned so as to make the most efficient use of the light available. This is particularly important in daylight signal indications but applies also to kerosene burners and battery-operated lamps that give night indications only.

A large variety of spreading and deflecting types of lenses and auxiliary cover glasses are in use for directing the rays toward the zone where a signal must be seen. A deflecting element is necessary to enable an engineer at very close range to see a signal which is mounted very high overhead, as in Fig. 13-45, or to see a dwarf signal which is close to the ground, as in Fig. 13-50. A deflecting or spreading element is necessary to provide visibility along a curved track approach.

Table 13-11. Essential Data on Lamps for Railroad Searchlight-Type, Color-Light Signals

LAMPS	VOLTS	WATTS	AXIAL BEAM CANDLE POWER	
			8¾-inch Fresnel lens	8¾-inch Compound lens
1000-hr rating	11.3	14.4		
Service rating	10.0	11.9	17,500	37,500
1000-hr rating	9.0	15.3		
Service rating	8.0	12.8	16,000	34,000
1000-hr rating	4.0	3.0	Not recom-	
Service rating	4.0	3.0	mended	11,000
1000-hr rating	10.0	5.0	Not recom-	
Service rating	10.0	5.0	mended	19,000

By making the front surface of lenses and semaphore signal roundels convex rather than flat, it is possible to scatter most of the external light reflected from the front surface of the lens so that it will give negligible interference with the function of the signal. Frequently flat auxiliary roundels inclined at specific angles, or other special means are used. The incorporation of reflectors in the optics of a signal unit involves particularly careful analysis to guard against reflected external light. Thus, a light-directing system that may be entirely satisfactory for ordinary spotlight or other special illuminating purposes may be extremely dangerous in a railroad signal since it can flash spurious indications. Hoods or visors projecting forward from light-signal units are always employed as an aid in reducing reflection from the sky and as a protection against snow and sleet interference.

Signal Colors

The colored elements in lights used in signaling systems in the United States are with a very few exceptions covered by Association of American Railroads specifications 59 and 69. The A.A.R. color specfications are explicit both as to the color of resulting signals and as to the color limit samples that are to be used for inspecting colored glassware. These specifications are defined in terms of the I.C.I. color diagram and in terms of a set of primary glass color standards maintained in the National Bureau of Standards at Washington, D. C. That Bureau certifies and issues duplicate working standards representing the permissible tolerance on color variation of signal glassware. (See Fig. 13-51.)

In color-light signaling, six distinguishable colors are considered possible: *red*, *yellow*, *green*, *blue*, *purple*, and *lunar white*. The use of blue and purple is very limited, because incandescent and kerosene light sources are very low in output in the blue part of the spectrum; hence, when the colored lens or roundel is put over the light, the resulting candle-

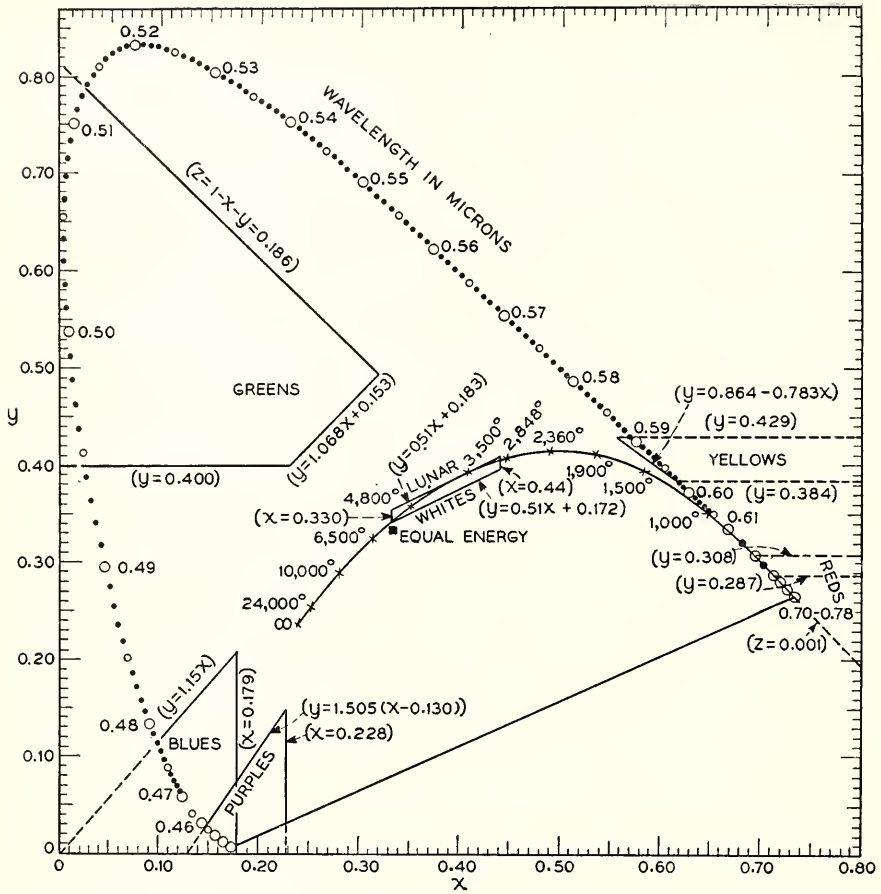


FIG. 13-51. Railway signal color specifications plotted on I.C.I. chromaticity diagram.

power is low and the signal range short. Lunar white is the name assigned to the colorless indication obtained by using a lens of light blue glass which makes the light appear a high color-temperature white instead of the usual yellowish kerosene or incandescent filament color. Lunar white thus provides assistance in distinguishing a white signal from ordinary nonsignal lights along the wayside.

As is commonly understood, red is associated with the most restrictive signal aspects, green with the least restrictive, and yellow with intermediate indications. For the specific meanings of the many signal aspects made possible by displaying two or more lights simultaneously, see the *Manual of the Signal Section of the A.A.R.* (Association of American Railroads).

The yellow used in position-light signals is a hue somewhat paler than that covered by A.A.R. specification for yellow color-light signals or

lantern purposes. This light yellow is distinctly different from nonsignal wayside lights. Railroad-grade-crossing red warning lights are maintained by the railroads and the color governed by A.A.R. specification.

AIRPLANE HANGAR LIGHTING

To design an adequate hangar-lighting system, it is necessary to consider both the quality and the quantity of illumination required for the various seeing tasks involved. Therefore, it is necessary to know first the ultimate usage of the hangar, i.e., whether it is for storage or for maintenance and repair. The values in Table 13-12 are considered to be minimum for efficient, safe, and accurate work.

Equipment Selection

Direct lighting equipment generally is considered to be most practical for hangar areas. This class of equipment may be used with incandescent-filament, mercury-vapor-discharge, or fluorescent lamps.

When using filament- or mercury-lamp equipment, care must be taken to avoid direct or reflected glare as these sources have a very high brightness. To minimize direct glare, reflectors should shield the lamp as indicated in Table 13-13. To prevent reflected glare, open-type filament or mercury units should not be used where the work surfaces have shiny or specular surfaces. Low-brightness luminaires are suitable where specular surfaces must be worked upon.

To obtain the best results from an installation: Easy access to all lighting units should be provided by installing lowering hangers, catwalks, or traveling monorail cranes. Luminaires should be accessible even when a hangar is full of airplanes.

A regular cleaning and lamp replacement schedule should be established.

Table 13-12. Recommended Minimum Average Maintained Illumination for Aircraft Hangars

PRINCIPAL OPERATION	FOOTCANDLES*
Engine repair	50
Frame repair	30
Instrument repair	50
Paint shop	20
Plane maintenance (general)	30
Radio repair	50
Recovering area	30
Storage (live)	10

* The footcandle values represent order of magnitude rather than exact levels of illumination.

Wherever possible and practical, the general lighting system should be designed to provide adequate illumination.

When internal work or shadowed parts around the planes cannot be satisfactorily lighted by the general lighting installation, supplementary luminaires should be used.

Table 13-13. Recommended Distribution Characteristics of Hangar Lighting Luminaires

LUMINAIRE	SHIELDING ANGLE	LIGHT DISTRIBUTION IN ZONES ABOUT VERTICAL AXIS (Per cent of total output)		
		0–30°	30–60°	60–90°
			Not less than	Not more than
For mercury or filament lamps:				
High-bay reflector	30.0°	25	50	12
Dome reflector	17.5°	25	50	20
Silvered-bowl diffuser (Filament lamps only)	15.0°	35	50	13
For fluorescent lamps	13.0°	25	50	20

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SECTION 14

PHOTOGRAPHIC, REPRODUCTION, PROJECTION, AND TELEVISION LIGHTING

The primary function of radiant energy in photography is to produce photochemical change in a photosensitive material such that subsequent processing will result in a satisfactory permanent image. It is desirable in most cases that the change be effected with a minimum expenditure of energy and, often, in the shortest possible time. Since photosensitive materials vary widely in their spectral and their absolute sensitivity, these factors influence the photographic applications of radiant energy sources. Infrared, ultraviolet, and x-ray radiation as well as light can be used to create a latent image.

Light sources, optical systems, and screens used for picture projection are planned in combination for a particular range of viewing distances and viewing angles and for a given range of surrounding brightnesses. The lighting design objective is to provide a capacity for creating realistic contrasts between high-lights and shadows on the screen at a satisfactory average brightness level.

Television-studio lighting problems are similar in many respects to those encountered on the dramatic stage and on the motion-picture-studio set. The required flexibility in illumination level and in illumination distribution over a wide range necessitates the use of many high candlepower sources. The color requirements depend on the type of television camera used.

Many of the lamps used in these fields are described in Sections 1 and 6. See Figs. 1-10, 6-1, 6-14, 6-15, 6-21, 6-23 to 6-27 and Tables 6-3 to 6-11. Additional data are given in Tables 14-1, 2, 3, 4, 5, and 6 and in Fig. 14-2.

Table 14-1. 115- and 120-volt Incandescent Photoflood or Superflood Lamps

DESIGNATION	APPROX. WATTS	RATED LIFE (hours at 115 volts)	RATED LUMENS	APPROX. COLOR TEMP. (K)	BULB	MAXIMUM OVERALL LENGTH (inches)	BASE
No. 1	250	3	8,650	3,400	A-21	$4\frac{15}{16}$	Medium
1B, B1 (blue bulb)	250	3	—	‡	A-21	$4\frac{15}{16}$	Medium
No. 2	500	6–8	17,000	3,400	PS-25	$6\frac{15}{16}$	Medium
2B, B2 (blue bulb)	500	6–8	—	‡	PS-25	$6\frac{15}{16}$	Medium
RFL-2, R2	500	6	4,500*	3,400	R-40	$6\frac{1}{2}$	Medium
RSP-2	500	6	†	3,400	R-40	$6\frac{1}{2}$	Medium
No. 4	1,000	10	33,500	3,400	PS-35	$6\frac{1}{2}$	Mogul
4B, B4 (blue bulb)	1,000	10	—	‡	PS-35	$6\frac{1}{2}$	Mogul

* Beam lumens within 0–30 degree zone. Maximum beam candlepower, 6500.
† Maximum beam candlepower, 50,000. Approximate beam spread to 10 per cent maximum candlepower, 15°–20°.
‡ Color of light balanced approximately to requirements of daylight color films.

NOTE: References are listed at the end of each section.

PHOTOGRAPHIC LIGHTING

Commonly used photosensitive films and plates include the following: Ordinary (mainly blue sensitive) Panchromatic (sensitive to all colors) Orthochromatic (sensitive to all colors except orange and red) Color (sensitive to all colors) Infrared (sensitive to red and infrared) Their spectral sensitivity curves are given in Fig. 14-1.

The practical problem of producing a latent image in one of these materials requires that the incident radiation be of a quality that includes wavelengths to which the material is sensitive and, further, that the quantity of incident radiant energy (exposure) be sufficient to effect an adequate photochemical reaction.

Table 14-2. 115- and 120-volt White Diffusing Bulb Incandescent Enlarger Lamps

RATED WATTS	RATED LIFE (hours at 115 volts)	INITIAL LUMENS (115 volts)	BULB	MAXIMUM OVER-ALL LENGTH (inches)	LIGHT CENTER LENGTH (inches)	BASE
75	25	1,125	S-11	$2\frac{3}{8}$	$1\frac{3}{8}$	S.C. Bay
75	100	1,300	A-21	$4\frac{15}{16}$	$3\frac{3}{8}$	Medium
150	100	3,100	A-21	$4\frac{15}{16}$	$3\frac{3}{8}$	Medium
			A-23	$6\frac{1}{16}$	$4\frac{1}{2}$	Medium
150	300	2,550	A-21	$4\frac{15}{16}$	$3\frac{3}{8}$	Medium
250	3	8,000	A-21	$4\frac{15}{16}$	$3\frac{3}{8}$	Medium
300	300	6,300	PS-30	$8\frac{1}{8}$	6	Medium
500	100	11,600	PS-30	$8\frac{1}{8}$	6	Medium
50 100 150	100	—	A-21	$4\frac{15}{16}$	$3\frac{3}{8}$	*

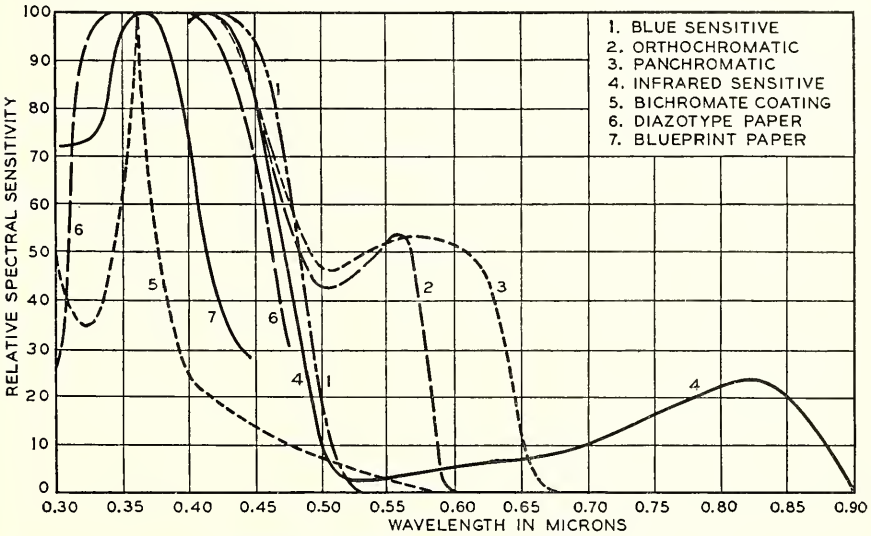
* Three-contact, medium-screw base lamp. Requires special socket.

Table 14-3. 115-, 120- and 125-volt Incandescent Lamps Designed for Operation at 3200 K

WATTS	BULB	MAXIMUM OVER-ALL LENGTH (inches)	LIGHT CENTER LENGTH (inches)	RATED LIFE (hours at 115 volts)	BASE
500	PS-25 IF	$6\frac{15}{16}$	$5\frac{1}{4}$	60	Med. Screw
500	T-20	$6\frac{1}{2}$	$2\frac{1}{2}$	35	Med. Bipost
500	T-20	$5\frac{3}{4}$	$2\frac{3}{16}$	30	Med. Prefocus
500	T-20	$5\frac{1}{2}$	3	30	Med. Screw
750	T-24	$6\frac{1}{2}$	$2\frac{1}{2}$	30	Med. Bipost
1,000	T-20	$9\frac{1}{2}$	$3\frac{7}{16}$	35	Mog. Prefocus
1,000	T-20	$9\frac{1}{16}$	$4\frac{3}{4}$	35	Mog. Screw
1,000	PS-40 IF	$9\frac{3}{4}$	7	60	Mog. Screw
1,000	G-40	$7\frac{1}{4}$	$3\frac{1}{2}$	35	Med. Bipost
1,000	G-40	$8\frac{7}{16}$	$3\frac{15}{16}$	35	Mog. Prefocus
1,000	G-40	8	$5\frac{1}{4}$	35	Mog. Screw
1,000	PS-52	$13\frac{1}{16}$	$9\frac{1}{2}$	75	Mog. Screw
2,000	G-48	9	$3\frac{15}{16}$	60	Mog. Prefocus
2,000	G-48	$8\frac{5}{8}$	$5\frac{1}{4}$	60	Mog. Screw
2,000	G-48	$9\frac{3}{8}$	5	60	Mog. Bipost
5,000	G-64	$11\frac{7}{8}$	$6\frac{1}{2}$	150	Mog. Bipost

Light Quality

The first essential, that the illuminant emit energy in the spectral region in which the photographic material is sensitive, is not alone sufficient. Even in black-and-white photography, color delineation in the form of faithful gray values is required. In black-and-white photography, the photographer endeavors to secure in its negative a scale of grays corresponding to the various brightnesses of the subject.



1 micron = 1/10,000 centimeter = 10,000 angstroms

FIG. 14-1. Spectral sensitivity curves for common types of photographic materials.

Table 14-4. Typical 115-, 120-, and 125-volt Incandescent Lamps Used for Motion-Picture-Studio Lighting

RATED WATTS	BULB	MAXIMUM OVER ALL LENGTH (inches)	LIGHT CENTER LENGTH (inches)	APPROX. COLOR TEMP. (K)	INITIAL LUMENS	RATED LIFE (hours at labeled volts)	BASE
10,000	G-96	$17\frac{3}{8}$	10	3350	327,000	75	Mog. Bipost
5,000	T-64*	$13\frac{3}{8}$	$6\frac{1}{2}$	3350	165,000	75	Mog. Bipost
2,000	T-48†	$10\frac{1}{2}$	5	3350‡	65,500	25	Mog. Bipost
2,000§	PS-52	$13\frac{1}{16}$	$9\frac{1}{2}$	3350	65,000	15	Mog. Bipost
1,500	PS-52	$13\frac{1}{16}$	$9\frac{1}{2}$	General Service Type 1000			Mog. Screw
1,000	PS-52	$13\frac{1}{16}$	$9\frac{1}{2}$	General Service Type 1000			Mog. Screw
1,000	G-48	$9\frac{3}{8}$	5	3150	25,000	100	Mog. Bipost
750	T-24	$6\frac{1}{2}$	$2\frac{1}{2}$	3350‖	24,500	12	Med. Bipost
500	T-20	$6\frac{1}{2}$	$2\frac{1}{2}$	3350¶	16,000	8	Med. Bipost
150	T-8	$3\frac{5}{8}$	$1\frac{1}{2}$	3050	3,300	25	D.C. Bay

* Available also in G-64 bulb with $11\frac{1}{4}$ inch M.O.L.
† Available also in G-48 bulb with $9\frac{3}{8}$ inch M.O.L.
‡ Available also with approximately 3265-K color temperature, in T-48 and G-48 bulbs, with reduced lumen output, 100 hour life.
§ 115-volt only.
‖ Available also with approximately 3210-K color temperature, with reduced lumen output, 50-hour life.
¶ Available also with approximately 3185-K color temperature, with reduced lumen output, 50-hour life.

Table 14-5. Typical Photoflash Lamps*

CLASSIFICATION	MFRS.' DES'G.	VOLTAGE RANGE FOR OPERATION	APPROX. TIME TO FULL PEAK (milliseconds)	FLASH DURATION AT ½ PEAK (milliseconds)	APPROX. LUMEN-SECONDS	APPROX. MEAN COLOR TEMP. (K)	BULB	MAXIMUM OVER-ALL LENGTH (inches)	BASE
F (Fast Peak)	SM	3	5	7	5,500	3,300	B-11	$2\frac{5}{8}$	S.C. Bay
	SF	3–9	5	4	5,000	3,400	B-12	$2\frac{3}{8}$	S.C. Bay
M (Medium Peak)	5	3	20	13	16,000	3,800	B-11	$2\frac{5}{8}$	S.C. Bay
	5B	3	20	13	7,000	6,000	B-11	$2\frac{5}{8}$	S.C. Bay
	Press 25	3–9	23	20	25,000	4,000	B-12	$2\frac{3}{8}$	S.C. Bay
	Press 25B	3–9	23	20	14,000	6,000	B-12	$2\frac{3}{8}$	S.C. Bay
	0	3–125	23	16	25,000	4,000	S-13	$3\frac{13}{16}$	Medium
	11	3	20	12	28,000	3,800	A-15	4	Medium
	Press 40	3–125	23	18	40,000	4,000	A-15	$3\frac{15}{16}$	Medium
	Press 50	3–125	23	16	50,000	4,000	A-17	$4\frac{1}{16}$	Medium
	22	3–125	20	14	60,000	3,800	A-19	5	Medium
	22B	3–125	20	14	26,000	6,000	A-19	5	Medium
	2	3–125	25	17	75,000	4,000	A-19	$4\frac{3}{4}$	Medium
	2B	3–125	25	17	42,000	6,000	A-19	$4\frac{3}{4}$	Medium
S (Slow Peak)	50	3–125	30	17	93,000	3,800	A-21	$5\frac{3}{8}$	Medium
	50B	3–125	30	17	40,000	6,000	A-21	$5\frac{3}{8}$	Medium
	3	3–125	28	21	140,000	4,000	A-23	$6\frac{5}{8}$	Medium
	3B	3–125	28	21	85,000	6,000	A-23	$6\frac{5}{8}$	Medium
FP (Focal Plane)	6	3		30	15,000	3,800	B-11	$2\frac{5}{8}$	S.C. Bay
	31	3		53	75,000	3,800	A-21	$5\frac{3}{8}$	Medium
	2A	3–9	23	50	80,000	4,000	A-21	$5\frac{3}{8}$	Medium

* See also Fig. 14-2.

Thus, it is necessary that the film and the illuminant complement each other. Where this is not possible, it is general practice to employ a filter at the camera lens to reproduce more accurately the brightness of the colors. Where mixed illuminants are used, one or the other must be filtered to give similar photographic results. The filtering process is always one of light absorptance, and frequently it is necessary to employ filters of only 25 to 50 per cent transmittance. An illuminant that requires a minimum of filtering thus is likely to have advantages.

For photography in color, the spectral quality of the illumination is even more critical. Color emulsions are "balanced" for use with a particular quality of light. Because most color photography materials are based on three emulsion layers, each sensitive to a relatively narrow spectral band, adjustment by filtering to an illuminant other than the one for which the material was originally intended calls for precise filter formulation.

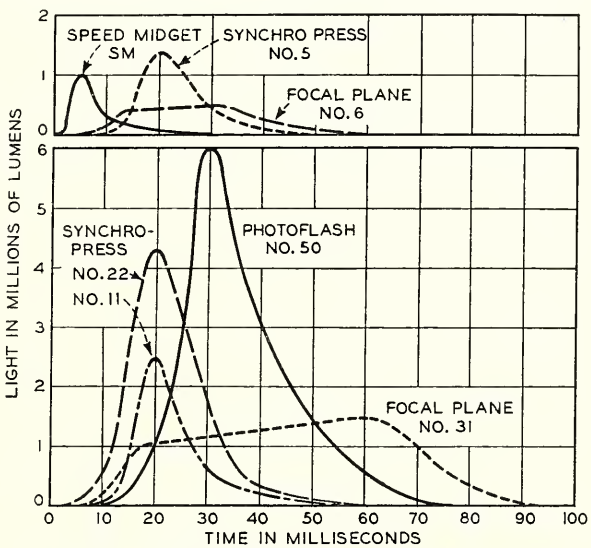


FIG. 14-2. Time-light curves for several photoflash lamps.

Table 14-6. Mercury-Vapor Discharge Lamps for Photography and Photoprocesses*

DESIGNATION	WATTS	WATTS PER INCH	APPROX. VOLTS (Operating)	APPROX. *AMPERES	LIGHTED LENGTH (inches)	OVERALL LENGTH (inches)	ARC TUBE DIAM (inches)	ARC TUBE MATERIAL
UA-4†	1,200	25	125	10.5	49	$55\frac{7}{8}$	$1\frac{1}{8}$	UVT Glass
A-H6‡	1,000	1,000	840	1.4	1	$3\frac{1}{8}$	$\frac{1}{4}$	Quartz
A-H9§	3,000	$62\frac{1}{2}$	535	6.1	48	$54\frac{7}{8}$	$1\frac{1}{8}$	Glass
Cooper Hewitt†	275	5.5	73	3.5	50	$55\frac{1}{2}$	1	Glass
OS-S2076‖	2,000	44	550	4.0	46	$52\frac{1}{4}$	$\frac{25}{32}$	Quartz
BOS-S2082‖	2,650	54	660	4.5	$48\frac{3}{4}$	54	$\frac{27}{32}$	Quartz
TS-S2081‖	3,450	74	885	4.35	47	$53\frac{3}{4}$	$\frac{15}{16}$	Quartz
MSS-S2078‖	4,400	103	960	5.10	$42\frac{1}{2}$	$48\frac{1}{2}$	$\frac{15}{16}$	Quartz
BMS-S2089‖	3,450	72	900	4.25	48	$53\frac{1}{2}$	$\frac{15}{16}$	Quartz

* Require auxiliary ballasts which provide proper circuit characteristics.
† For blueprinting and copyboard lighting including printing on diazo or black and white paper.
‡ For vacuum frame printing.
§ For copyboard lighting.
‖ For blueprinting and printing on diazo or black and white paper.

Light Quantity or Exposure

The quantity of light that a film receives is a function of object brightness, of time, and of lens aperture.

Exposure equals *illumination at the film* × *time*. This relationship frequently is referred to as the reciprocity law. It holds true, fairly well, for the exposure times encountered in most photographic work. Exposure time may be governed by factors such as the necessity for stopping motion, flashlamp and flashtube characteristics, and subject reflectance, which fix the amount of light available. In many situations the object brightness is fixed and the time of exposure and lens aperture must be adjusted, as, for example, out-of-doors.

Two major factors affecting the amount of light required are:

1. The light-transmitting ability of the camera lens.
2. The absolute sensitivity of the film.

The most common system of expressing the light-gathering power of a lens is the *f*-system in which the *f*-value of a lens is given as the *focal length* ÷ *the diameter of the lens opening*. Since the light transmitted is proportional to the area of the opening, the *inverse of the square* of the *f*-value is a measure of the light-collecting ability of a camera lens. The illumination on the film will be influenced also by surface reflections, glass absorptance, and vignetting.

There are a number of systems in vogue for evaluating the absolute speed of film and plates.[1] The American Standards Association has standardized a procedure for determining film speed which appears to include all of the factors necessary in obtaining satisfactory prints, and should eventually come into general use.[2]

The following formula, embodying the reciprocity law and the factors of lens aperture and film rating, gives the relationship of the several elements affecting exposure for objects of average reflectance:

$$E = \frac{K \times f^2}{T \times S}$$

where E = Illumination on subject being photographed (in footcandles).
f = *f*-value at which the lens aperture is set.
S = Speed of film, according to the A.S.A. system. (The older Weston and G.E. exposure meter values also applicable with adjustment of K.)
T = Time of exposure (seconds).
K = A constant based on the various elements used. 15 is a satisfactory value for negatives of average density (A.S.A.). (Weston $K = 10$) (G.E. $K = 20$)

Instead of basing the exposure on incident illumination, the average brightness B may be substituted for E if a corresponding change is made in K.

Photoelectric Exposure Meters

The formula above is the basis of exposure meter design and operation, since all exposure meters of the photoelectric-cell type are essentially brightness-measuring devices. However, some may be used also as illuminometers to measure the illumination on the subject. (See Section 5.) The meter consists of a photovoltaic cell, an ammeter of high sensitivity, and a calculator. A hood or louver is provided in front of the sensitive cell to limit the acceptance angle to approximately 30 degrees, a rough average of the angle intercepted by the lenses of both still and movie cameras.

The customary method of using a photoelectric exposure meter (brightness type) is to hold it near the camera and point it toward the subject, thereby assuming that the meter "sees" the area being photographed much as does the camera lens. Frequently a scene may include large areas, such as an open sky or a dark surrounding doorway, that may result in a brightness indication on the meter scale having little relation to the brightness of the subject. An under- or overexposure of the subject will result unless the proper precautions are taken. These include holding the meter at such a distance from the subject as to include only the subject.

The design of some meters permits the removal of this hood so that the cell will respond to illumination from an almost 180-degree solid angle when making illumination measurements. When using a meter of this type, a different method (often called the incident-light method) is used. The meter is held close to the subject but pointed in the general direction of the camera. The meter reading indicates the illumination on the subject. Meters of this type usually include a provision in the calculator for arriving at the correct shutter speed and lens aperture. If not, the formula given on page 14-6 can be applied.

In motion-picture photography the lens aperture forms the only variable, inasmuch as the exposure time is fixed by picture frequency. Exposure meters designed for this work give *f*-numbers for a specific film speed.

Guide number system. Since it is not practical to employ exposure meters in connection with the use of flash lamps, there has come into general use a system of guide numbers which greatly simplifies the statement and use of exposure information in connection with these sources. (See Table 14-7.)

The five important elements affecting exposure in flash photography are:

1. Brightness of the subject (affected by light output of flash source used, reflector used, reflectance of subject).
2. Film rating.
3. Shutter timing.
4. Distance from the light source to the subject.
5. Lens aperture.

Table 14-7. Guide Numbers for Flash Photography*

(To obtain the lens-aperture setting (the *f*-number); divide the guide number by the lamp-subject distance, in feet)

FLASH LAMP OUTPUT (lumen-seconds)	FILM RATING†					SHUTTER SPEED (seconds)
	A.S.A. 5	10	20	40	80	
	Weston 4	8	16	32	64	
	G.E. 6	12	24	48	100	
4,500	28	40	56	67	128	T,B,1/25,1/50‡
to	21	30	42	56	84	1/100
6,300	19	24	38	47	76	1/200
	14	17	28	34	56	1/400
6,300	35	50	70	100	140	T,B,1/25,1/50
to	28	38	56	77	112	1/100
9,000	22	30	44	60	88	1/200
	15	22	30	44	60	1/400
9,000	40	56	80	112	160	T,B,1/25,1/50
to	31	44	62	88	124	1/100
12,500	25	35	50	70	100	1/200
	17	25	34	50	68	1/400
12,500	45	60	90	120	180	T,B,1/25,1/50
to	37	45	75	90	150	1/100
18,000	27	38	54	75	108	1/200
	19	28	38	55	76	1/400
18,000	55	68	110	135	220	T,B,1/25,1/50
to	42	60	84	117	168	1/100
25,000	37	48	75	95	150	1/200
	27	34	55	67	110	1/400
25,000	70	100	140	200	280	T,B,1/25,1/50
to	55	78	110	155	220	1/100
35,000	44	60	88	120	175	1/200
	30	44	60	88	120	1/400
35,000	80	113	160	225	320	T,B,1/25,1/50
to	62	88	125	175	250	1/100
50,000	50	70	100	140	200	1/200
	35	50	70	100	140	1/400
50,000	85	120	170	240	340	T,B,1/25,1/50
to	65	92	130	185	260	1/100
70,000	55	75	110	150	220	1/200
	38	55	75	110	150	1/400
70,000	110	135	220	270	440	T,B,1/25,1/50
to	85	117	190	235	380	1/100
100,000	75	85	155	190	310	1/200
	55	65	110	135	220	1/400
100,000	135	165	270	330	540	T,B,1/25,1/50
to	*These lamps not used with synchronizers*					1/100
140,000						1/200
						1/400
140,000	165	270	330	540	660	T,B,1/25,1/50
to	*These lamps not used with synchronizers*					1/100
200,000						1/200
						1/400

* For all lamps except focal plane.
† For Kodacrome A use A.S.A. 5. For Kodacrome B use A.S.A. 10.
‡ T = time. B = bulb.

A photographer usually has a particular size or sizes of photographic flash lamp and reflector, a particular type of film, and an established practice as to the shutter speed he prefers to use. Thus, items 1, 2, and 3 are fixed and it is possible to combine them empirically to provide a guide number that is the product of the aperture (*f*-number) and the distance (feet) from subject to lamp. Since these are both second power functions and in inverse relationship, it remains merely to divide the guide number by the distance from lamp to subject to obtain the aperture setting. It becomes a simple matter to remember the guide number applicable to a particular lamp, film, and shutter speed. The guide-number system has been found useful also in conjunction with other illuminants, when an exposure meter is not available.

Photographic Lighting Equipment

Reflectors. It is common practice, with cameras not having interchangeable lenses, to choose a lens with a focal length approximately equal to the diagonal of the film used. This results in the picture area subtending an angle of about 45 degrees. Likewise, it is customary to place the lighting equipment near the camera or, at least, at about the same distance from the subject.

Reflector beam patterns. Reflector beam patterns for complete light utilization should fill an angle of about 45 degrees. However, it is well to minimize difficulties caused by inaccurate aiming of the reflector by filling a 60-degree cone. An ideal reflector distribution would be one that provides uniform illumination throughout the 60-degree field, then "cuts off" completely, but such a design is not readily attained. A reflector whose candlepower value at 30 degrees from the axis of the beam is 50 per cent that at the center is considered to have a 60-degree spread. Such a beam pattern provides lower illumination toward the edges of the picture, but this is seldom objectionable since the point of interest in a picture is in the middle and a lower exposure at the edges is not serious.

A bare lamp emits about 6 per cent of its light output within a 60-degree solid angle. Even the poorest of reflector designs will utilize 12 to 15 per cent of the light emitted by a lamp and a well-designed reflector should project 30 to 35 per cent in a 60-degree cone as compared with only 6 per cent for a lamp alone. A good reflector and one lamp thus can provide as much light on a subject as do six bare lamps.

The shadows and contrasts that help to light a person as we normally see him are usually "soft," such as are produced by a light source of appreciable size. Large reflectors (16 to 24 inches in diameter) produce more natural modeling and should be used in portrait studios as well as commercial establishments where their size is not a handicap. Cameras carried by newspaper photographers, and many cameras used by amateurs have lamps and reflectors attached and thus there is a premium on compactness. The reflectors for these usually are 5 to 7 inches in diameter. Miniature-camera flash equipment often employs even smaller reflectors (4 to 5 inches) more in keeping with the size of the camera. These smaller reflec-

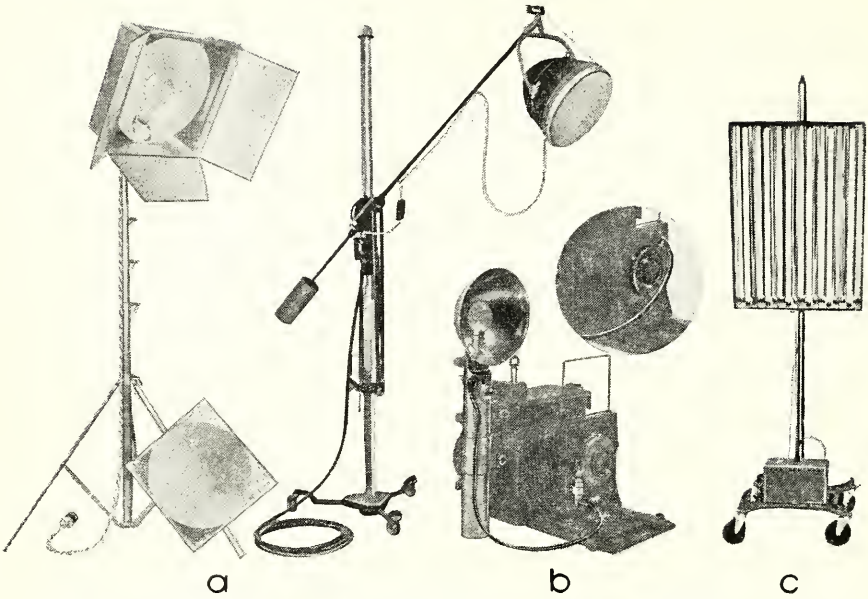


FIG. 14-3. Typical photographic lighting reflectors: a. portrait studio types; b. camera mounted types with shutter-lamp synchronizers; c. fluorescent lamp type.

tors produce somewhat unnatural, sharp shadows. Figure 14-3 shows a number of typical photographic-lighting reflectors.

Reflector materials and finishes that are used in photographic equipment include aluminum, and plated or enameled surfaces. Aluminum has been the most popular material for several reasons. It weighs little. With proper treatment, the reflecting properties of its surface may be made anything from highly specular to totally diffusing. Its reflectance is as high as that of any other practicable material. When an anodizing treatment is used to brighten and protect the surface, the original reflectance is made quite permanent.

Other materials used include chromium or rhodium plating, and white enameled steel; however, the resulting equipment is heavier and the reflectance lower. It is not possible to concentrate light effectively with a white enameled steel reflector.

The inside-frosted bulb, such as is used with photoflood-type lamps, does not completely diffuse light from the incandescent filament and usually it is necessary to give reflectors intended for these lamps a somewhat diffusing surface to eliminate striations and smooth out the resulting illumination. Photographic-flash lamps, on the other hand, are large-area diffuse sources (flash fills bulb) and therefore polished-surface reflectors should be used. Since flashtube dimensions are relatively large, also, they usually are best employed with polished reflectors.

Reflector shape. Reflector shape affects beam control and light utilization. A deep reflector, of approximately paraboloidal or ellipsoidal con-

tour, will have a shorter focal length than a shallow one of the same diameter and therefore will intercept and direct into the beam a larger percentage of the light emitted by the source. Reflectors should be as deep as practical for greatest efficiency.

Reflectors for fluorescent lamps usually are of a trough type. Such reflectors do not control the light in the plane of the axis of the lamp. However, in a plane perpendicular to the lamp axis, control of the light distribution can be as accurate as that obtained with practical "point sources."

Lens spots. The lens spotlight frequently is used to provide a high level of illumination over a limited and well-defined area. It is employed by professional motion picture, commercial, and portrait photographers and (in small sizes) by amateurs. In its usual form, it consists of a lens of either plano-convex or Fresnel type behind which is placed a concentrated source such as an arc or an incandescent lamp. (See Fig. 14-4.)

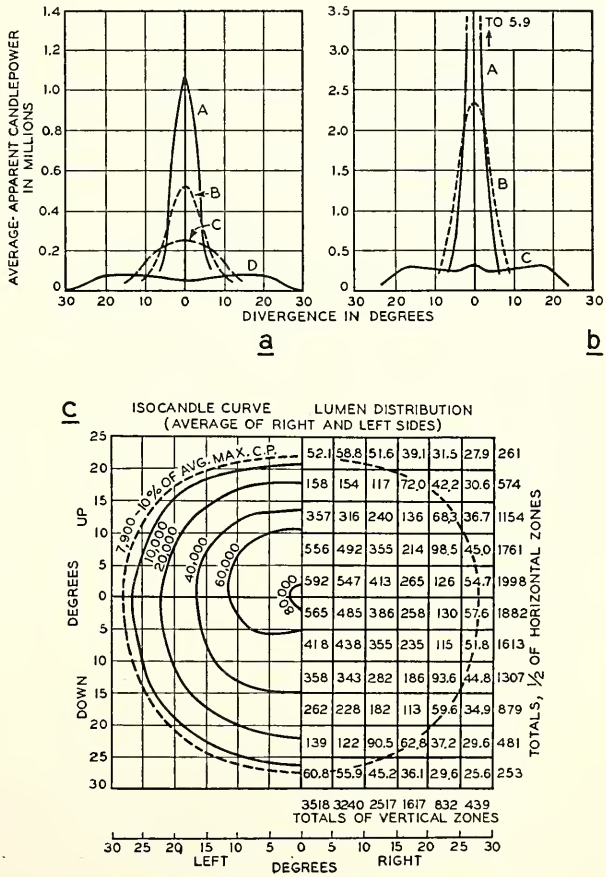


FIG. 14-4. Lighting performance of typical spotlamps used in motion picture and television studios:

a. 5000-watt incandescent-lamp-type lens spotlamp, known as a "senior solar spot." The curves show candlepower distribution related to **A** 13° beam, 18,000 lumens; **B** 20° beam, 19,000 lumens; **C** 30° beam, 26,500 lumens; **D** 60° beam, 47,000 lumens.

b. High intensity 115-volt d-c arc lamp type lens spotlamp (140–145 arc amperes, 60–70 arc volts). The curves show candlepower distribution related to: **A** 10° beam, 47,000 lumens; **B** 18° beam, 75,000 lumens; **C** 48° beam, 130,000 lumens.

c. 1,000-watt A-H 6 mercury-vapor-lamp-type spotlamp. Isocandle curves and the distribution of lumens in the beam are shown on the graph.

For incandescent-lamp spots, a spherical mirrored reflector is used behind the lamp to redirect back through the source light that otherwise would be wasted. Control of spot size is obtained by movement of the source to and from the lens.

Flashlamp synchronizers. The photographic flashlamp has been adopted universally by newspaper photographers and others who must take pictures independently of a central power source. In such service an automatic device that synchronizes the flash of a lamp and the opening of a camera shutter is needed. (See Fig. 14-3.) It is desirable to operate the camera shutter at speeds of 1/100 to 1/200 of a second in order to minimize the effect of any other illumination. Since approximately 5 milliseconds is required for a shutter of the pre-set type to reach full opening and 20 to 23 milliseconds for the lamp to reach peak light output, the synchronizing device must first apply the current to the lamps and then 15 to 18 milliseconds later trip the shutter.

Two or three flashlight-type dry cells customarily are used to supply the igniting power. Within two or three milliseconds (0.002 to 0.003 second) a flashlamp filament is heated to a sufficient temperature to ignite the priming material with which the filament and adjacent lead wires are coated. In the case of the primer-type lamps, called "SM" or "SF" by different manufacturers, the flash of the primer material provides the entire light output, which reaches a maximum intensity approximately 5 milliseconds after the closing of the circuit. In the case of lamps filled with shredded aluminum or aluminum alloy wire, the burning primer sends a shower of sparks through this material, initiating its combustion at about 10 milliseconds. The burning foil or wire reaches peak light output at about 20 to 23 milliseconds for the smaller and average-size lamps and at 30 milliseconds for the largest size. (See Table 14-5 and Fig. 14-2.)

APPLICATION OF LIGHT AND LIGHTING EQUIPMENT TO PHOTOGRAPHY

Providing light for photography differs in several fundamental respects from lighting for vision. The chief difference is in the level of illumination, which is of the order of 10 times that provided for vision. The second difference is the uniformity of illumination required. Successful photography requires a rather narrow range of illumination so that both the brightest parts (highlights) and the darkest parts (shadows) will be fully and satisfactorily rendered in the final photograph. This range is much narrower than can be used for vision, particularly in the case of color photography.

Another general requirement of photographic lighting arises from the monocular vision of the camera. To compensate for the lack of stereo depth, the best lighting on photographic subjects emphasizes their roundness, form, and spatial relationship. This is largely a matter of lighting direction, such as lighting from the side or the back.

When a black-and-white print is viewed, the eye naturally seeks contrast and unconsciously attempts to tie up contrast in the print with the contrast

that experience has shown to be in the original subject. When this contrast is lacking, the picture immediately loses its potential aesthetic appeal.

A person with normal vision sees an object with two eyes and thus from two different points simultaneously. The two images produced on the retinas are different, and this disparity is automatically rationalized and interpreted by the mind as form or roundness. Thus, in binocular vision, contrast is not necessary to create a sense of roundness. In a photograph, however, the camera "sees" the subject from a single point and therefore cannot record form except by illusion. This illusion arises as follows: Wherever a depression or elevation occurs on a surface illuminated by directional light, a shadow is formed. Thus a highlight *plus* a shadow is interpreted by the mind as a depression or an elevation. When a subject is illuminated by diffuse light alone, that is, by light from all directions, no shadows can be formed. An extreme case of this is an uneven field of fresh snow. On an overcast day, there are no shadows and the field looks perfectly flat. On a sunny day, however, each little depression and elevation has its shadow, and these shadows are immediately interpreted as evidence of uneven terrain.

A general requirement peculiar to color photography is that the color temperature of all of the light sources used must be the same or very nearly the same. It is not practical to use light sources of widely differing color temperatures if faithful color rendition is desired. The eye readily accepts illumination of mixed color temperature. Photographic film does not. This requirement complicates some lighting situations, for example, where daylight must be supplemented by light from electric sources.

In photography, two types of illumination are needed to produce a likeness of a subject:

1. *General illumination*, if used alone, produces a negative that is flat and without modeling. Such illumination does not produce prominent shadows, and density differences in the negative are caused for the most part by differences in the reflectance of various portions of the subject. This general, over-all illumination goes by several names, among which are front light, broad light, flat light, camera light, basic light, and others.

2. *Modeling light*, if used alone, produces a negative in which the highlights can be well exposed but the shadows are clear and show no detail at all. Modeling lights are usually highly directional and are used for the express purpose of casting shadows and forming highlights.

Outdoors, general illumination, especially in the shadows, is furnished by sky light and by light reflected by the surroundings. The modeling or directional light is furnished by direct sunlight. Outdoors a certain amount of lighting control can be achieved by the judicious use of reflectors. White cardboard or cloth can be used to reflect light into the shadows while mirrors can be used to produce sharp shadows and highlights. In professional motion-picture photography out-of-doors, even in sunlight, supplementary electric sources often are used to raise the illumination level in shadowed areas.

Background brightness. A factor closely related to lighting is background brightness. For ordinary subjects, the background should not be very dark, very light, or too close behind the subject; neither should it be of exactly the same brightness as important parts of the subject, because such a condition would have the effect of merging the subject with the background. The less detail and the fewer the distracting spots in the background, the better.

Portrait Photography

The portrait photographer is concerned with photographing people either singly or in groups. In a case of individuals or groups of two to four he endeavors carefully to model the subjects with lights to make a pleasing and natural likeness, possessing "roundness" and "depth." This he does with the aid of shadows, highlights, and contrasts.

Photography of Lighting Installations

The making of pictures of interiors and exteriors using the regular, permanently installed lighting does not require special photographic materials or equipment. Larger cameras such as the 8-by 10-inch or 5- by 7-inch view types are appropriate. Smaller cameras such as the 4 by 5 inch and $2\frac{1}{4}$ by $3\frac{1}{4}$ inch sizes can be used, provided they possess adequate adjustments. The small miniature camera usually is not suitable. In any case, a good lens is needed. It should be coated to reduce flare and improve shadow detail. Care is needed in assuring sharp focus and proper exposure. The camera should be supported on a tripod. The pictures should be made at a small lens aperture (such as $f/16$) to obtain sharpness everywhere in the picture. The exposure time should be determined with an exposure meter. Film development and printing procedure should follow the manufacturer's recommendations except in the case of subjects in which there are a wide range of brightnesses such as interiors in which luminaires are in the camera field. The technique for such cases is explained on page 14-18. Several possibilities and limitations of lighting installation photographs are illustrated by Figs. 14-5 to 14-9.

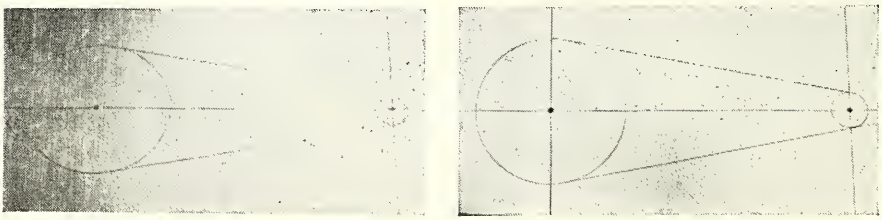


FIG. 14-5. Photography to show reflected glare, a, and appropriate lighting, b. The subject is a scribed drawing on metal. A brightness measurement made with an exposure meter held somewhat in front of the camera is as significant as any other measurement for this type of subject. The important point in photographing a reflected glare spot is that the picture be taken from the eye point of the worker. Otherwise, the reflected image will appear in a different area of the work. The same thing applies to photographing a correctly lighted area. If the camera viewpoint differs radically from the observer's viewpoint, glare spots out of the normal field of view may be included in the photograph.

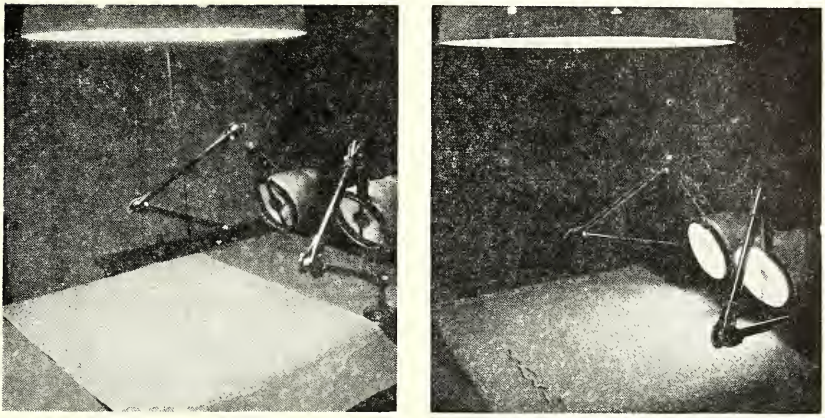


FIG. 14-6. Photography to compare the effect of lighting direction on the apparent texture of a surface. Picture *a* was taken to show the effect of overhead lighting alone. Picture *b* shows the increased texture detail visible when the light is applied at grazing incidence. No attempt was made to light the surroundings which therefore are lost in picture *a*. They could be seen easily in the original subject. Even less of the surround is visible in picture *b* because the lighted area is even brighter than in *a*. When surroundings are important, supplementary illumination can be added.

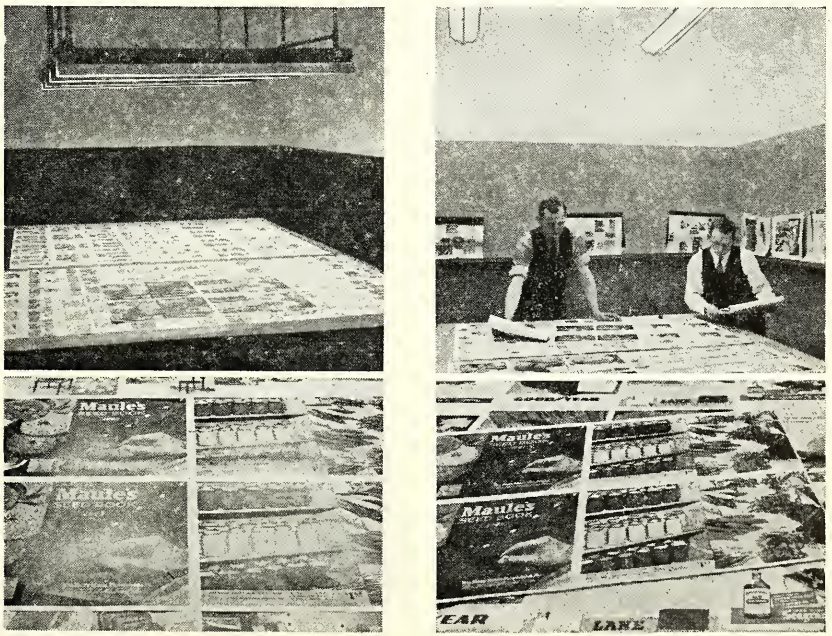
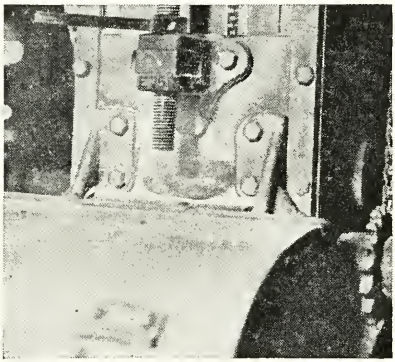


FIG. 14-7. These pictures permit comparison of inspection lighting of press proofs. A low mounted bank of lamps, (left), causes glare from the press proof, whereas the more general illumination from a higher mounting, (right), does not. Pictures that include luminaires require full exposure and short time film development.

The engineer should not expect to make brightness measurements from negatives or prints unless all the requirements of photographic photometry[1, 3] are understood and met.

Limited brightness rendering of the photographic process. Photographic films and plates can record a very wide brightness range, far greater than can be reproduced in a single print. A glossy paper print has a practical brightness range limit of about 1 to 40. Even within this range, brightness differences are not reproduced uniformly. There is an unavoidable decrease in brightness differences at both ends of the scale. If the brightness range of the subject is greater than 1 to 40, either one or both ends of the



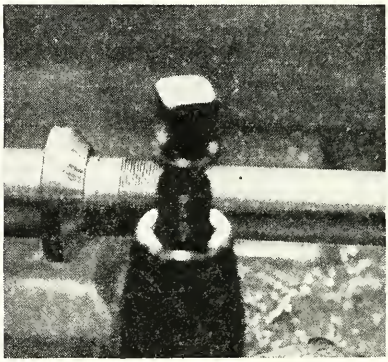


FIG. 14-8. Extreme closeups of locally lighted areas frequently impose a problem in picture sharpness. The range of distance in sharp focus, known as depth of field, is extremely limited in closeups and the smallest lens opening on the camera should be used. Note that the cover in picture at left and the tool post in picture at right are out of focus. Sharper pictures probably could be attained by more careful focusing on the ground glass and by the use of a smaller lens opening. Small cameras have an advantage over larger ones for such pictures, since they have greater depth of field at the same lens opening, other things being equal.





FIG. 14-9. The effect of supplementary illumination: Picture at left was taken with no added illumination. Even though the room was well lighted, note that the lower desk areas appear to be dark. In picture at right photoflood supplementary illumination was added as described in the text and has resulted in improved illumination of the desks in the foreground. Both pictures were taken with a surface-treated lens.

brightness scale will be lost, or the whole scale can be compressed so that all brightness differences are decreased. A print can be made to select whichever type of rendering is desired, by choice of paper contrast grade, appropriate exposure, and so on. In usual scenes, shadow detail is desired and the print made accordingly.[4] The highlight details of some illumination setups may be more desired than shadow details, and appropriate prints can be made.

Black-and-white transparencies differ from paper prints in that they can reproduce a much greater brightness range, and can render correct brightness differences over a greater part of this range. Color transparencies tend to emphasize brightness differences throughout most of the scale in the interests of fidelity in color saturation.[5]

Preparing for a photograph. The making of pictures of the results of a given lighting installation differs from the photography of a scene or object as such. The normal procedure of a photographer is to place his lights to show the object to best advantage, to obtain uniform illumination that falls within the brightness range of the photographic process, and, by the lighting direction and placing, to convey roundness, form, and spatial relationship to compensate in part for the lack of stereo depth in monocular camera vision. A photographic illumination level may be made of the order of 10 times that required for comfortable vision in the interest of a short exposure time. A lighting installation, on the other hand, usually has fairly static illumination designed for seeing, not photography.

Because of the limitations in the photographic process, particularly in paper prints, which are of most practical interest, the photographer should make his negatives with certain precautions. If proper reproduction of both highlights and shadows is desired, it is important to keep the maximum brightness range of the subject below 100 to 1. It is important also to reduce lighting contrasts in the scene to allow for adaptations made by the eye as it scans the scene.[3]

Therefore, it may be necessary to add supplementary illumination to the darker parts of the scene to obtain a photograph that approaches the visual impression of the scene. The photography of a near-by face in sunlight illustrates the point—facial shadows are not noticed in the original subject but in photographs they seem unnaturally dark. If the surroundings of the principal illuminated object or the shadows in it are important, additional light is needed, but must be added in such a way that the intended effect is not spoiled. In such cases the rendering is much improved by light added to the shadows by reflectors or by a flashlamp or tube at the camera. Assuming the correct exposure time has been determined for the existing illumination, if a flash lamp is to be used near the camera, the basic exposure should be decreased by a time equal to half the usual exposure for a flashlamp near the camera. If this is not convenient, either the next smaller lens aperture (larger number) or a 50 per cent greater flashlamp-subject distance than the usual recommendation will do. The first result may not be satisfactory, but it will indicate the next step.

Use of exposure meters. In professional studio photography, the pre-

vailing practice, especially in color work, is to read illumination, and to make allowance for unusually high or low subject reflectance. This practice probably is sound where most of the illumination comes from near the camera. In other cases, and these are frequent in lighting installations, it is probably better to read brightness, and to make sure that the meter cell is close enough to the subject to receive light only from the illuminated area of interest.

If the whole brightness range is to be reproduced, the exposure meter can be used to scan the subject and thereby aid in obtaining proper illumination for a desirably limited brightness range.

Approximate exposure guide for interiors. The following data may be found convenient for rough survey pictures, or if an exposure meter is not at hand. The use of film having an exposure index (tungsten-filament source) of 64 is assumed. A tripod or other camera support is needed.

For brightly illuminated stores, offices, drafting rooms, and other such interiors, expose 2 seconds at $f/16$. For interiors of average brightness such as homes, factories, schools, etc., expose 10 seconds at $f/16$. For dimly lighted storage rooms, basements, and some restaurants, expose 3 minutes at $f/16$. If there is any doubt as to the brightness class of the subject at hand, make a series of three pictures differing in exposure. One should have the suggested time, the other two should have $\frac{1}{4}$ and 4 times as much. One or more of the series usually will be printable.

Photographing installations to include luminaires. One type of picture frequently desired is that of an illuminated office, store, factory, or other interior with the luminaires appearing in the photograph. The presence of these bright objects extends the brightness range of the subject, and it is this high brightness range that demands a departure from usual photographic technique.

The camera should take film at least 4 by 5 inches in size, preferably larger. A coated camera lens is desirable but not vital. Such a lens tends to eliminate "flare" around the luminaires in a picture, and it produces better shadow detail than an untreated lens.

A low-contrast sheet film should be used, and it should be exposed 4 times the normal determined by a photographic exposure meter measuring illumination at table height. The films should be developed two-thirds of the normal time.

The negative should be printed in the usual manner except that some "dodging" may be necessary.

It may be desirable to add a small amount of supplementary illumination to the room. The desirability of supplementary illumination depends on the purpose of the photograph. In any case it assists in obtaining negatives which can be printed more readily. The brightness range reproducible in a photographic print is definitely limited, and such a print may not do full justice to a room that is lighted in a visually satisfactory manner. The print may make the darker areas seem too dark. On the other hand, if the illumination is truly uniform, then the effect will be reproduced quite well in the print. If supplementary illumination is desirable, the use is

suggested of a No. 1 photoflood lamp in a reflector over the front of which is draped several thicknesses of handkerchief (not to be allowed to touch hot bulb, which may char or burn it). This source will add light to shadow areas in the foreground without casting noticeable shadows itself.

When making "before and after" photographs to show improvement in illumination, the "before" setup should be the subject of a series of exposures. This series can be 4 times, 2 times, $\frac{1}{2}$, and $\frac{1}{4}$ normal. All the negatives should be printed, and the print that most closely approximates the visual appearance of the subject can be chosen. The problem in making these "before" pictures is that with adequate camera exposure and with careful dodging in the print, the illumination can be made to appear much more uniform than it actually is. The use of this exposure series technique and careful printing from the most appropriate negative can yield a result that approximates the visual effect. A good photographer always tends to improve the appearance of a poorly lighted room unless he understands that such a distortion is not desired.

Photography and Limits of Visibility

The question sometimes arises—can photography duplicate a certain visibility? This is of particular interest in court cases involving traffic accidents at night in providing evidence on what a car driver could see.[3]

It is at first necessary to differentiate between what the driver *could* see and what he *would* see. Assuming it is desired to know what he could see, the following procedure may prove practical. The scene is reconstructed in as much detail as practicable, including the headlights concerned, and other contributing factors. Several observers make notes from the driver's viewpoint as to details visible in the distance or in the margins of the headlight beam. A series of photographs is taken from the driver's eye-point at exposure times of 30 seconds, 1 minute, 2 minutes, and 4 minutes, all at $f/4.5$ on a fast panchromatic film. The best possible print is made from each negative. The observers then choose the picture most closely approaching what they saw for court presentation.

It should be noted that, unlike adapted vision, the photographic process is cumulative with time in its effect. Exposures much longer than those mentioned will record details that the eye could not see. Much shorter exposures will not record as much as the eye can see.

Commercial Photography

For work out of the studio, a photographer takes much of the studio lighting equipment with him. Where lighting needs are severe, as for large interiors, 2,000-watt moviefloods are used in reflectors suspended along the walls.

Similar reflectors, wired to a common connecting cable, and equipped with No. 22 or No. 50 photoflash lamps, form the more or less standard lighting arrangement of the banquet photographer. An approximate rule of thumb is: one No. 50 lamp for each 500 square feet of floor area with a lens aperture of $f/16$ and fast panchromatic film.

Professional-Motion-Picture Photography

Lighting of professional-motion-picture sets has reached a very high stage of development. Cameramen who are artists with light play an important part in the success of a picture. The lighting equipment must be extremely versatile and be capable of producing a wide range of illumination levels. Frequently, large areas must be lighted, necessitating many powerful sources. Since an increasing number of pictures are being made in color, the spectral quality of the light must be held within close limits. This is particularly important because it is common practice to light the same set by means of more than one type of illuminant.

Both arc and incandescent sources are used. In the former the color control is achieved in the materials with which the electrodes are impregnated. Filters are used with incandescent lamps to achieve the desired color. Typical equipment is shown in Figs. 14-3 and -10.

Common motion picture set lighting practice is to flood a set with general illumination to increase shadow area brightness and reduce average exposure time required and then add (for modeling) spotlighting equipment

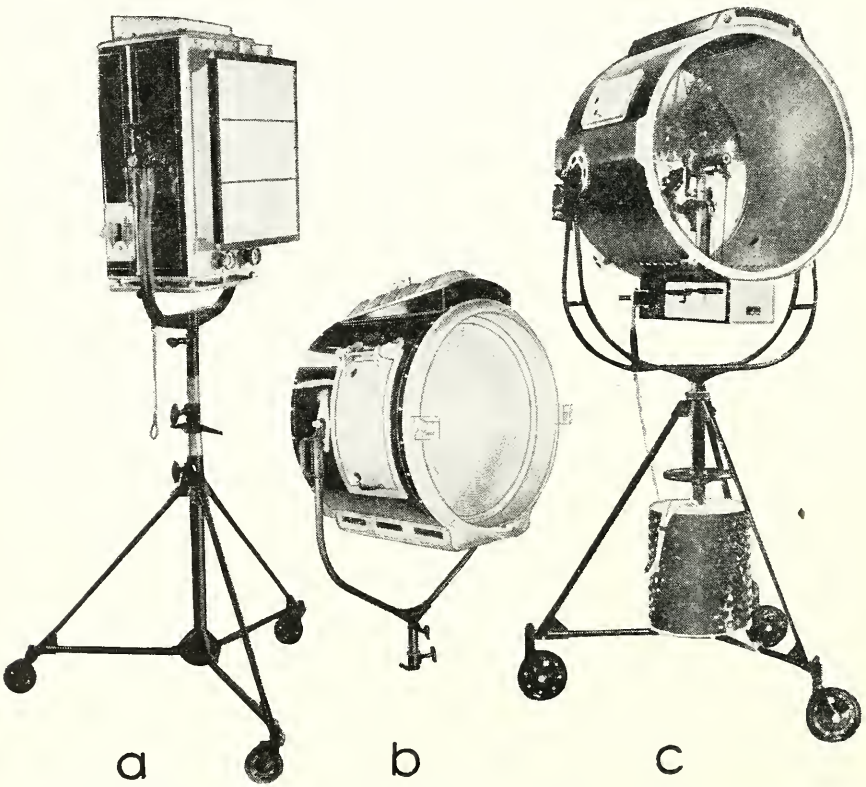


FIG. 14-10. Typical motion picture studio equipment: a. twin arc broadside with diffusing screen in place; b. high intensity spot; c. sun arc.

which may be mounted on platforms placed along the top of the set walls or on the floor in the vicinity of the camera. To this foundation the cameraman adds variations he feels are needed to interpret a picture properly.

Sound pictures are photographed at the rate of twenty-four pictures per second and silent pictures at the rate of sixteen pictures per second. The camera shutter covers the lens at least 50 per cent of the picture cycle so the exposure time for each sound picture is $\frac{1}{48}$ second or less and for silent pictures less than $\frac{1}{32}$ second. With lens apertures of the order of $f/2.5$ and currently available films, approximately 100 to 200 footcandles of general illumination and about 2 to 4 times this value of modeling illumination are required. Color film calls for a level of from 250 to 700 footcandles general illumination and for somewhat lower brightness contrasts because of the limited exposure latitude of color films.[7]

Motion-picture-studio lighting equipment. The equipment used for motion-picture-studio lighting is of two general types—spotlight and floodlight. Spotlights may employ either Fresnel lenses or glass or polished metal reflectors. By adjustment of the light source along the optical axis, beam divergences of from 8 to 50 degrees are obtained. (See Figs. 14-4 and 14-10.) The floodlights ("broadsides" or "broads" as they are known in studio parlance) may have a beam spread of almost 180 degrees.

For "close-ups" and smaller sets, the broadsides supply the general illumination and the spots the modeling light.

The spotlights, opened to their wider beam divergences, are employed frequently on the medium-size and larger sets to supply general illumination as well as that for modeling, because of the greater distances involved.

Electrical illumination frequently is used to supplement daylight in out-of-door or on-location scenes. This is done to secure adequate illumination in shadows, accentuate principals, improve modeling, and in some cases change shadow direction.

For this purpose, spotlighting equipment generally is employed and in the case of black-and-white photography the discrepancy between the color quality of the artificial source and daylight seldom is important. Both arcs and incandescent sources must be filtered to produce a close match to daylight for color photography.

PHOTOCHEMICAL REPRODUCTION PROCESSES

Contact and projection printing (enlarging), photocopying, diazo printing and blueprinting, and the graphic arts processes of photo-engraving, lithography, and photogravure are photochemical reproduction processes.[8] (See Table 14–8.)

Darkroom Lighting

In general, the radiation from a darkroom illuminant should be of such quality as will not appreciably fog photosensitive material during the time required for its manipulation. No darkroom light source is absolutely safe, and all types will cause fogging if given sufficient time. Consequently,

Table 14-8. Photochemical Reproduction Process Data for Flat Copy Lighted with Filament Lamps, Electric Discharge Lamps, or Arcs

PROCESS	AREA TO BE LIGHTED (inches)	PHOTOSENSITIVE MATERIAL	WAVELENGTH LIMITS OF USEFUL SENSITIVITY (microns)*	LIGHT SOURCE NUMBER AND TYPE	EXPOSURE WITH GIVEN ILLUMINANT	
					Approximate Incident Radiant Energy in Active Band† (watts per square foot)	Time (seconds)
Photocopying Contact printing	11 x 14 (max)	Chloride paper	0.32–0.5	1 (a) 1 to 6 (b) 9 to 36 (c) 9 to 36 (d) 2 to 8 (e)	0.14	3–5
Projection enlarging	Up to 8 x 10 negatives	Bromide paper Chlor-bromide paper	0.35–0.51	Diffuse Lighting 1 (f)	0.17–0.46	10–30
				Specular Lighting 1 (g) 1 (h)	8	3–5
Phototemplates (making negative)	5 ft x 10 ft (max)	Orthochromatic plates	0.35–0.55	2–4 (i) 2–4 (j)	—	30–60
Enlarging on metal plate	12 x 24	Gelatin silver	0.32–0.5	17 (k) 17 (l)	—	5
Record copying	Copyboard 11 x 14 to 40 x 50	Record copy paper	—	2 (m) or 2 (n) 4 (o)	—	10–15
Photogravure (making negative)	Copyboard 30 x 40	Orthochromatic and panchromatic film or plates	0.35–0.55 0.35–0.7	4 to 8 (m)	0.16	2–4

Making positive transparency by contact printing	Vacuum frame	Process film or plates	0.3–0.55	1 (s)	—	5–20
Making carbon tissue image	Vacuum frame 20 x 30	Bichromate sensitized carbon tissue	0.3–0.5	2 or 4 (t) 1–4 (h)	20	3–4 min
Blueprinting Contact printing Continuous single print	Paper from rolls up to 42 in. wide, moving 2 to 24 ft per minute; also cut sizes	Blueprint paper	0.3–0.44	1 or more (q, u) 4–5 (v)	80–260	6–20
Diazo printing Continuous single print	Same as blueprinting	Diazo paper (B&W paper)	0.35–0.48 different colors vary within this range	1 or more (u)	40–130	6–20

* In all photoprocesses glass or plastic is interposed between the lamp and the light-sensitive material, as a lens or as a contact plate. Glass lenses do not transmit appreciable energy of wavelengths shorter than 0.35 micron and glass contact plates do not transmit below 0.3 micron, hence these values are given as the lower limit of the useful range, although many materials are sensitive well below 0.3 micron.

(a) 500- to 1,000-watt, 115-volt, general-service, clear bulb lamps.
(b) 60-, 75-, or 100-watt, 115-volt, general-service, inside-frosted lamps.
(c) 2½-watt, 115-volt, S-14 bulb, argon-glow lamp.
(d) 4-watt, RP-12 bulb, 360BL fluorescent lamp.
(e) 15-watt, 18-in., T-8 bulb, 360BL fluorescent lamp.
(f) For amateur service: photographic enlarger lamps. For commercial and general service: photographic enlarger lamps; also 1000-watt, 115-volt, PS-52 bulb enlarger lamp.
(g) 1,000-watt, 115-volt, G-40 bulb, mogul-prefocus base, spotlight lamp.
(h) 1,000-watt, quartz lamp, type A-H6.
(i) 25- to 50-ampere arc lamp using 8- to 22-mm, white-flame carbons.
(j) 3,000-watt, 48-in., low-pressure mercury lamp, type A-H9.

† Much of the activation during exposure is effected by radiant energy in the near ultraviolet region and relatively little in the visible part of the spectrum. Consequently lumens, footcandles, and candlepower inadequately express the effective energy for a given emulsion. The figures represent the amount of energy (within the wavelength range in which the material is sensitive), *incident* (per square foot) *on printing, copyboard, or transparency surface*, not input watts to the light source.
(k) 30-watt, 36-in., blue fluorescent lamp.
(l) 30-watt, 36-in., 360BL fluorescent lamp.
(m) 40-watt, 48-in., daylight fluorescent lamp.
(n) 350-watt, 56-in., Cooper Hewitt lamp.
(o) 500-watt 115-volt, reflector photoflood lamp.
(p) 1,500-watt, 115-volt, T-24 inside-frosted-bulb photoengraving lamp.
(q) 1,200-watt, 49-in., low-pressure mercury lamp with ultraviolet transmitting bulb.
(r) 100- to 150-ampere, high-intensity arc with rotating electrode.
(s) 50-, 100-, and 200-watt, 115-volt, general-service, daylight-blue inside-frosted lamp.
(t) 35-ampere arc lamp using white-flame carbons (two or four arcs in one lamp).
(u) 55 and 76 watts per in. loading low-pressure mercury lamps with quartz bulb.
(v) 5- to 25-ampere arc lamps with blueprinting carbons.

only enough illumination should be made available for the photographer to see what he is doing. Materials should not be exposed to the light more than is absolutely necessary.

Darkroom illumination may be provided by either of two methods: incandescent lamps with colored bulbs, or darkroom "safelights" containing an ordinary uncolored lamp.

Red or amber bulb coatings applied either inside or out have not been satisfactory because of the difficulty of preventing pin holes. For this reason the natural dark amber and natural ruby bulbs are recommended for darkroom incandescent sources not to be used in "safelight" luminaires. Manufacturers of natural colored bulbs usually provide two types, the light amber and ruby intended for general lighting such as exit and signal lights, and dark or photographic amber and ruby. The latter type should be specified for darkroom installation.

PICTURE PROJECTION LIGHTING

Satisfactory picture projection requires not only careful selection of light source and optical elements for projecting the picture but also of the screen and its surroundings in relation to the seating area from which it is to be viewed. The basic requirement is that the picture brightness shall be of a value such that the proper contrasts of highlights and shadows are achieved at a satisfactory over-all level.[9] Some illumination in the seating area is essential for the convenience of the audience, safety, discipline etc. However, if light from the seating area is allowed to fall on the screen the desired contrasts are reduced, and the over-all brightness must be increased to restore the proper relations.

The logical place to start in planning picture projection is the area in which the pictures will be shown. This establishes the brightness level, the type of screen to be used, and the amount of light needed from the projector.[10]

Brightness Levels

Brightness levels recommended by the Society of Motion Picture Engineers are predicated on the presence of minimum stray light on the screen itself and a practicable balance between characteristics of photographic materials and available light. The following screen brightness standards apply to motion-picture projection with the shutter operating but with no film interposed at the aperture, and are applicable to all viewing angles within the seating area.*

Theater projection: 10^{+4}_{-1} footlamberts, at the center of the screen.

Classroom projection: 5 to 20 footlamberts, for all parts of the screen.

No values have been standardized for slide projection. However, the preceding values are applicable generally not only for still pictures in a darkened room but also for slides or charts in only partially darkened rooms.

* "Screen Brightness (35-MM)," *Z-22.39-1944*, American Standards Association, New York, N. Y.

Screen Surfaces

Their respective reflectance characteristics determine the condition under which the four general classes of screens can be used to satisfy the preceding brightness recommendations.

1. *Matte surface screen.* Matte surface screens reflect incident light in such a way that their brightnesses are substantially the same at all angles of view—hence they are recommended where the viewers occupy a wide angle. A surface coated with a flat white paint has this characteristic. Several screen materials are available which produce a similar result (Fig. 14–11 curve). This type is required in practically all theaters because of the wide viewing angles and is recommended for classrooms for the same reason.

2. *Beaded screen.* The surface of a beaded screen is covered with small glass spheres which reflect the major part of the light back in the direction from which it came, as shown in Fig. 14–11 curve. To observers sitting near the axis of projection, pictures on beaded screens are several times brighter than pictures on a perfectly reflecting matte screen. To observers about 22 degrees off the axis of projection, pictures seen on both types would appear equally bright, except that the far side of the beaded screen would appear somewhat brighter than the near side. This brightness difference is greatest at the shorter viewing distances. Such screens rarely are used for theater projection because they do not satisfy the brightness requirements

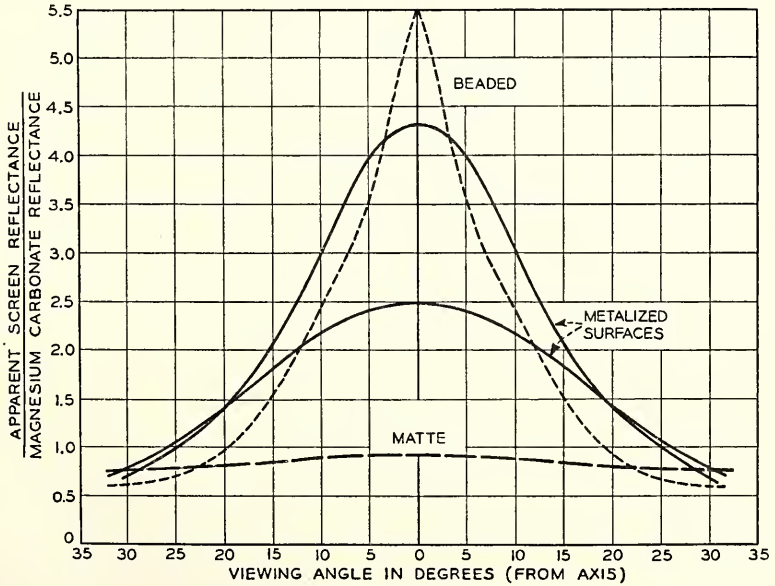


FIG. 14-11. Reflectance characteristics of screer surfaces. The reflectance values shown are expressed as a per cent of the reflectance of a magnesium carbonate block. The reflectance of a fresh clean magnesium carbonate surface is approximately 98 per cent.

of the entire normal seating area, particularly where the projection booth is well above the audience level. In classroom projection, on the other hand, the axis of projection is only slightly above eye level and such screens are used to obtain higher picture brightnesses when viewing positions can be kept within about 22 degrees of the projection axis. It is particularly important to observe the minimum viewing distance recommendations given at the foot of this page.

3. *Metalized screen.* The surface of metalized screens is coated with fine particles of metal, usually aluminum, each of which reflect light specularly. (See curves Fig. 14–11.) Such screens show a pronounced "hot spot" which is near the center of the screen for those near the axis of projection. The hot spot moves toward the near side of the screen as the observer moves away from the axis. Brightness differences increase with viewing angle and with reduction in viewing distance and are excessive for either classroom or theater projection. Metallic screens are necessary, however, for viewing polarized projected pictures.

4. *Translucent screen.* As its name implies, the characteristic of the translucent screen is to transmit light. The material used must be sufficiently thin so that there is a minimum loss of definition in the projected image and yet sufficiently diffusing to satisfy the requirements of brightness uniformity through the desired angle. When completely diffusing, their properties are essentially the same as those of the matte screen, but the brightness is less for a given amount of incident light. Translucent screens of high transmittance approximate the characteristics of metalized screens; a "hot spot" becomes increasingly apparent as the transmittance is increased.

Since such screens are primarily transmitters rather than reflectors of light they have the important advantage of being effective under higher levels of illumination in the audience part of the room than could be tolerated for a reflecting screen. A large portion of any stray light falling on the front of the screen passes through and thus causes less loss of contrast in the projected picture. On the other hand, extraneous light behind the screen is detrimental.

Maximum and Minimum Viewing Distance

At a viewing distance greater than 6 times the width of the screen, picture details are not satisfactorily resolved. Picture widths should equal approximately one-sixth of the distance from the screen to the farthest row of seats. (See Fig. 14-12.)

If the observer is sitting too close to the screen,[11] nervous strain and physical fatigue result from imperfections in the projected image and excessive eye movement in attempting to scan the entire screen area. In addition, when beaded screens are used, viewing from too short a distance increases the nonuniformity of screen brightness because of the large angle subtended by the scene. For classroom use,[12] seats should not be closer to the screen than twice the picture width in any case, and when beaded

screens are used a slightly greater minimum viewing distance ($2\frac{1}{4}$ to $2\frac{1}{2}$ times picture width) is better. The Society of Motion Picture Engineers recommends that, in motion picture theaters, the front row of seats should not be closer to the screen than 0.87 times the picture width.

Limitation of Viewing Angle

To avoid objectionable distortion of the projected picture, viewing angles should be limited to 30 degrees from the normal to the screen. This condition is fulfilled approximately when no row of symmetrically arranged seats is longer than its distance from the screen. (See Fig. 14-12.)

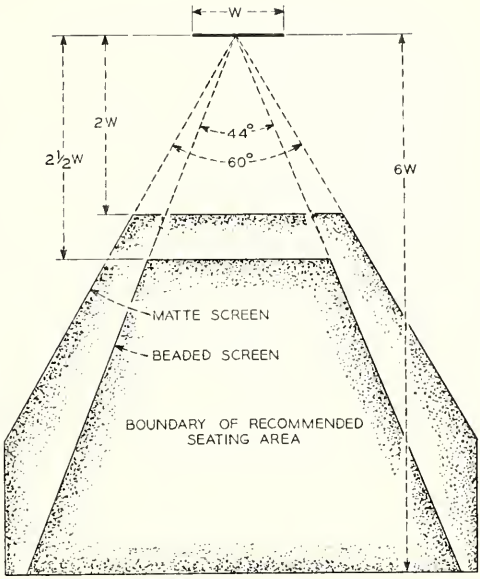


FIG. 14-12. Recommended seating area for comfortable viewing and acceptable brightness uniformity for various types of screens.

Projection Screen Dimensions

The ratio of height to width for theater screens corresponding to the proportions of 35-millimeter film should be 3 to 4.

For 8-millimeter and 16-millimeter, motion-picture film the same ratio of picture height to picture width applies; but, for classroom use, a square screen usually is preferable since it may be used also for the projection of slides, in which the greater dimension may be either horizontal or vertical.

Projection Booths

For detailed information on the design and facilities recommended for the projection room, it is suggested that the reports of the Projection Practice Subcommittee of the Society of Motion Picture Engineers be studied. See, for example, the September, 1942, *Journal of the Society of Motion Picture Engineers.*

Required Light Output of Projectors

In order to determine the required light output of a projector, it is necessary to know the picture size that satisfies the viewing conditions and the average reflectance at the applicable viewing angles of the screen to be used. With this information, the lumens required to meet the brightness recommendations can be calculated by the formula:

$$\text{Lumens} = \frac{\text{desired brightness (footlamberts)} \times \text{area of screen (square feet)}}{\text{Average reflectance (a decimal)}}$$

Classroom projection. Lumens-at-screen values to satisfy the recommended brightness values for classroom projection are given in Table 14-9 for several screen sizes. Only one set of values is given for beaded screens because the brightness differences encountered over the range of viewing positions embrace the recommended brightness range.

Motion-picture-theater projection. In order to ensure a sufficient screen brightness for proper viewing conditions, Standard Z-22.39-1944 published by the American Standards Association specifies: "The brightness in the center of a screen for viewing 35-millimeter motion pictures shall be 10^{+4}_{-1} footlamberts when the projector is running with no film in the gate." A projector light source of very high brightness must of necessity be employed in order to ensure conformance with this standard. In addition, the light source must be of a color quality permitting the faithful rendition of colored motion picture productions.

For these reasons carbon arcs are used almost universally in the projection of 35-millimeter motion pictures. Carbon arcs ranging in brightness up to 100,000 candles per square centimeter are available. They may be made to produce light having a color approximately represented by an equal energy spectrum. This is adapted to the projection of color transparencies.

Table 14-10 gives data on various screen and projector combinations.

Relation of Source Size and Optical System to Screen Illumination

In all except opaque picture projectors the lenses or reflectors used to illuminate the picture aperture are designed so that an image of the light source is formed in or near either the projection lens or the picture aperture. If the luminous portion of the source is imaged in either the projection lens or the picture aperture it is desirable to have the image size fill that element. If it is smaller, either the full light-collecting ability of the system is not being utilized, or the entire picture area is not illuminated. If it is larger, all of the available light is not being utilized and the excess

Table 14-9. Lumens-at-Screen Requirements for Classroom Projection

SCREEN SIZE (feet)	MATTE SCREENS		BEADED SCREENS
	Lumens for 5 Footlamberts	Lumens for 20 Footlamberts	Lumens for 5–20 Footlamberts
2.5 x 3.33	55	210	45
3 x 4	75	305	65
3.75 x 5	120	475	105
4.5 x 6	170	690	150
5.25 x 7	235	940	205
6 x 8	305	1,225	265
6.75 x 9	385	1,540	340
7.5 x 10	480	1,915	415
9 x 12	690	2,750	600
10.5 x 14	935	3,745	815
12 x 16	1,230	4,920	1,070

Table 14-10. Screen Illumination Provided by Typical Carbon-Arc, Motion-Picture-Projection Systems

CARBON				ARC		LAMP OPTICAL SYSTEM	SCREEN LUMENS‡	FOOTLAMBERTS AT SCREEN CENTER§					SCREEN LUMENS‡	BRIGHTNESS RATIO‖	FOOTLAMBERTS AT SCREEN CENTER¶				
Positive		Negative						10 feet	15 feet	20 feet	25 feet	30 feet			10 feet	15 feet	20 feet	25 feet	30 feet
Diameter (millimeters)	Length (inches)	Diameter (millimeters)	Length (inches)	Amp	Volts														
12	8	8	8	32	55	10 in. diam $f/2.3$ Mirror*							2,500**	70	15.6	7.0			
Low Intensity													3,400††	70	21.1	9.4			
7	12 or 14	6	9	40	27.5	11⅜ in. diam $f/2.5$ Mirror*	4,600**		11.9	6.6			5,000**	65		14.7	8.3		
							5,900††		15.3	8.6			6,500††	65		19.2	10.8		
7	12 or 14	6	9	42	33	14 in. diam $f/2.3$ Mirror*	4,900**		12.8	7.2			5,500**	60		16.0	9.0		
							6.600††		17.1	9.6			7,500††	60		21.8	12.2	7.8	
7	12 or 14	6	9	50	37	14 in. diam $f/2.3$ Mirror*	6,400**		17.0	9.5			7,200**	60		21.5	12.0	7.7	
							8,600††		22.4	12.6	8.0		10,000††	60			16.6	10.6	
8	12 or 14	7	9	60	36	14 in. diam $f/2.3$ Mirror*	7,600**		20.2	11.4	7.3		8,200**	65			13.4	8.5	
							10,300††			15.2	9.7		11,000††	65			18.2	11.6	8.1
8	12 or 14	7	9	70	40	14 in. diam $f/2.3$ Mirror*	9,600**			14.4	9.2		10,600**	65			17.7	11.3	7.9
							13,000††			18.8	12.0	8.3	14,000††	65				14.3	10.0
13.6	22	$\frac{7}{16}$ in.	9	125	68	Condenser Lenses at $f/2.0$*	7,500**		19.6	11.0	7.0		9,200**	65			14.8	9.5	
High Intensity							11,500††			16.6	10.6	7.4	14,500††	60				15.3	10.6
13.6	22	½ in.	9	150	78	Condenser Lenses at $f/2.0$*	11,000**			16.5	10.6	7.4	13,000**	60				14.0	9.7
							16,000††				14.8	10.3	19,500††	60					14.6
13.6	22	½ in.	9	170	75	Condenser Lenses at $f/2.0$*	11,000**			16.5	10.6	7.4	13,000**	65				13.5	9.3
							18,500††				16.6	11.5	21,500††	60					16.4
6	8½	5.5	6	30	28	10¼ in. diam $f/1.6$ Mirror†							2,300‡‡	70	14.4	6.4			

* 35-millimeter film projection system, 0.600 x 0 825 inch aperture.
† 16-millimeter film projection system, 0.284 x 0.380 inch aperture.
‡ Screen lumen figure is for systems with no shutter, film, or filters of any kind.
§ Footlambert figure at center of screen assumes 50 per cent shutter transmittance, a perfectly diffusing screen with 75 per cent reflectance and no film or filters of any sort; system adjusted so brightness at side of screen equals 80 per cent that at center. Screen width in feet is listed.
‖ Brightness ratio refers to ratio of brightness at side of screen to that at the center.
¶ Value with system adjusted to produce maximum brightness at the center of the screen.
** 5.5-inch effective focal length $f/2.5$ uncoated lens.
†† 5-inch effective focal length $f/2.0$ coated lens.
‡‡ 2-inch effective focal length $f/1.6$ uncoated lens.

Table 14-11. Picture Sizes Obtained with Various Lenses and Projection Distances

LENS-TO-SCREEN DISTANCE (feet) ...		5	10	15	20	25	30	35	40	50	70	80	100	150
Focal Length of Lens (inches)	Type of Projector	SIZE OF PICTURE												
		ft in.	ft in.	ft in.	ft in.	ft in.	ft in.	ft in.	ft in.	ft in.	ft in.	ft in.	ft in.	ft in.
½	8 mm	W 2 0 H 1 6	3 9 2 9	5 8 4 3										
1	8 mm	W 1 0 H 9	1 10 1 5	2 10 2 2	3 9 2 10	4 8 3 6	5 8 4 3							
	16 mm	W 1 10 H 1 4	3 9 2 10	5 8 4 2	7 6 5 6	9 4 6 11	11 6 8 7	13 4 9 11	15 0 11 2					
2	16 mm	W 1 0 H 9	1 10 1 4	2 10 2 1	3 10 2 10	4 8 3 6	5 8 4 3	6 6 4 10	7 6 5 7	9 4 6 11				
	35 mm	W H			8 2 5 9	10 2 7 5	12 3 8 9	14 4 10 4	16 4 11 9	20 5 14 9	28 6 29 0	32 9 24 0	41 1 30 0	
3	16 mm	W H	1 3 11	1 10 1 4	2 6 1 10	3 2 2 4	3 8 2 9	4 4 3 3	5 0 3 9	6 4 4 8			12 8 9 5	18 8 13 11
	35 mm	W H			5 5 3 9	6 9 4 9	8 2 5 9	9 6 6 9	10 9 7 9	13 6 9 9	19 1 13 9	21 9 15 8	27 4 19 8	
	Miniature Slide	W H	4 8 3 0	7 0 4 7	9 4 5 11	11 7 7 6	14 0 9 1		18 6 12 2	23 2 15 0				
3½	35 mm	W H			4 8 3 5	5 9 4 2	7 0 5 1	8 2 5 9	9 4 6 9	11 7 8 5	16 4 11 9	18 0 13 6	23 5 17 0	
4	16 mm	W H		1 4 1 0	1 10 1 4	2 4 1 9	2 10 2 1	3 2 2 4	3 10 2 10	4 8 3 6			9 6 7 0	14 0 10 0
	35 mm	W H			4 1 2 9	5 1 3 8	6 2 4 4	7 1 5 2	8 2 5 9	10 3 7 5	14 3 10 4	16 4 11 9	20 6 14 9	
	Miniature Slide	W H	3 7 2 2	5 4 3 5	7 1 4 4	8 9 5 9	10 7 6 10		14 0 9 1	17 7 11 8				
	Slide	W H	9 1 7 3	13 9 11 0	18 5 14 9	23 1 18 6	27 9 22 3		37 2 28 1	46 6 37 3	65 2 52 4	74 10 59 4	93 4 83 0	
6	35 mm	W H					4 1 2 9	4 6 3 4	5 4 3 9	6 9 4 9	9 0 6 9	10 9 7 9	13 6 9 9	
	Miniature slide	W H	2 4 1 5	3 6 2 2	4 7 3 0	5 10 3 9	7 1 4 4		9 2 5 11	11 7 7 6				
	Slide	W H	5 11 4 9	9 1 7 3	12 2 9 9	15 3 12 3	18 5 14 9		24 8 18 1	36 11 24 9	43 6 34 10	49 9 39 8	62 0 49 9	
8	35 mm	W H							4 1 2 9	5 2 3 8	7 1 5 2	8 2 5 9	10 2 7 4	
	Miniature	W H	1 10 1 1	2 8 1 9	3 7 2 2	4 6 2 11	5 3 3 5		7 1 4 4	8 11 5 10				
	Slide	W H	4 4 3 6	6 8 5 5	9 1 7 3	11 5 9 2	13 9 11 0		18 5 14 9	23 1 18 6	32 5 26 0	37 1 29 8	46 5 37 2	
10	Slide	W H	3 5 2 9	5 4 4 3	8 0 5 9	9 1 7 3	10 11 8 9		16 8 11 9	18 5 14 9	25 11 20 0	29 8 23 9	37 2 29 9	
20	Slide	W H	1 6 1 3	2 6 2 0	3 5 2 9	4 4 3 6	5 4 4 3		7 2 5 9	9 1 7 3	12 10 10 3	14 8 11 9	18 5 14 9	

wattage results in unnecessary heat. The same general relationships exist when the source is imaged near either the projection lens or the aperture. For each projector design there is an optimum source size.

There is no harm in using source sizes smaller than that required to fill the projection lens in those cases where the source is imaged in or near the projection lens if the amount of light obtained is sufficient for the projection conditions. In fact, the use of such smaller sources is desirable in such cases because of the economy of the reduced wattage. The important point to remember is that there is no advantage in using sources that are too large for the projection system because they do not provide any significant increase in screen illumination.

There are several methods for determining the utilizable source size:

1. If a source of diffuse illumination is provided directly in front of the projection lens, light will pass back through the optical system and form a spot at the source position. The size and shape of this spot defines the utilizable area.[13]

2. The source ordinarily used in the projector can be used in its proper position and the correctness of its size can be determined by looking back into the projection lens. An aerial image of the source will be seen in the lens. It should fill the picture aperture completely. When using this method it is necessary either to dim the source or to view it through some transparent light-absorbing medium.

3. A variation of the second method is to use a supplementary lens to project on a convenient screen an image of the source. Its size in relation to its associated aperture can thus be observed.

If the projection system is of a design such that the source is imaged at the picture aperture the source or that part which lies within the aperture must have a high order of brightness uniformity so that the screen may be evenly illuminated.

Screen Size Tables

Table 14-11 shows the size of projected pictures that result from several combinations of projection lens focal lengths and projection distances for various types of motion picture and slide projectors.

TELEVISION STUDIO LIGHTING

Lighting practice in television studios is (1947) in a transient condition, largely because rapid developments are taking place in all television equipment. This is particularly true in the case of transmitting apparatus and picture "pickup" devices.

The list of applicable illuminants and lighting methods is changing with the advent of pickups of greater sensitivity and altered spectral response. Television in color brings with it many of the problems of color-motion-picture photography.[14]

The heart of the pickup equipment, in one form, is called the iconoscope. Other types are the image orthicon and the dissector tube. The light-sensitive mosaic surface of the pickup tube can be likened to the film area of

the motion-picture camera. The television camera likewise includes a conventional lens for the purpose of forming on the mosaic an image of the scene being televised.

Iconoscope

Figure 14-13 illustrates the spectral response of an iconoscope used in present-day television studios.[15] With a lens aperture of $f/4.5$, illumination levels in the range 700 to 1,200 footcandles are required on the set.

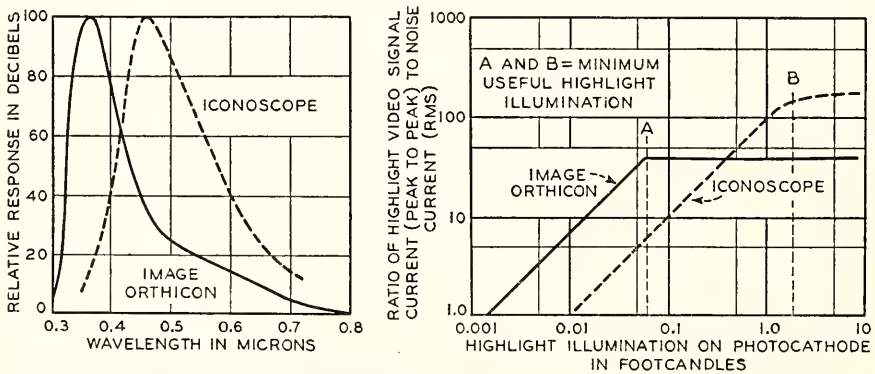
Comparison of the sensitivity characteristics of the iconoscope with the spectral energy distribution of the mercury-vapor arc will suggest the possibility of efficient energy utilization. However, in a television picture produced by this combination the monotone rendering of colors will be badly distorted. Blue and violet will be unduly emphasized while green and yellow will appear to be of unnaturally low brightness. Reds will appear black.

There is less distortion of the brightness scale when incandescent lamps are used, though the spectral character of their output emphasizes reds and yellows. In spite of the high blue and violet sensitivity of the mosaic coating, these colors appear dark and the over-all light utilization is less efficient.

Both the white flame and the high intensity carbon arcs used in motion-picture photography emphasize blues and violets also, but these lamps produce a fairly satisfactory scale of grays representing greens, yellows, and reds.

Both mercury- and carbon-arc sources will supply the required levels of illumination with much less discomfort caused by heat on the set than that caused by incandescent lamps.

Fluorescent lamps possess many advantages from the standpoint of light quality, particularly as the color of the light in a television studio could be controlled by employing a combination of lamps of several colors, adjusted to fit the iconoscope characteristics. However, currently available fluores-



1 micron = 1/10,000 centimeter = 10,000 angstroms

FIG. 14-13. Relative sensitivity curves for the iconoscope and image orthicon television pick up tubes.

cent lamps are not capable of supplying the illumination levels required by the iconoscope and therefore are not used at present except in conjunction with carbon or mercury arcs.

Lighting Methods

Lighting practice for television sets follows, in many respects, the methods used in motion picture studios.[16] The television cameraman endeavors to provide a flood of illumination throughout the set with general-lighting equipment, then models with spotlights. The practical difficulty in carrying out this arrangement is that the level of general illumination must be so high that it is difficult to add 2 or 3 times this value as is done regularly on the motion-picture set. The high radiant energy density on the actors causes unbearable discomfort. As a result, very little modeling is attempted.

The Image Orthicon

World War II development of television pickup devices, incorporating the electron multiplier principle, has resulted in the availability of the image orthicon.[17] The absolute sensitivity of this pickup is at least 10 to 20 times that of the conventional iconoscope. These tubes are used exclusively for field work and are being accepted rapidly for studio work also despite the present fidelity advantages of the iconoscope.

The general adoption of pickup tubes of higher sensitivity is of considerable significance to the lighting engineer. Levels of general illumination of from 50 to 100 footcandles are adequate for image orthicon pickup and are easily obtainable. Likewise, levels of 200 to 300 footcandles that can be provided with ease by spotlights will permit full play of the cameraman's skill.

The relative spectral sensitivity of the image orthicon is quite similar to that of the iconoscope (Fig. 14-13). White fluorescent lamps or possibly combinations of several colors may be used to provide adequate general illumination of a satisfactory color quality.

Fluorescent Lighting

General illumination should be provided by lamps mounted on the ceiling and so arranged that much of the light comes from the lamps located well out in front of the area where the action occurs so as to light the actors' faces effectively.

Some additional general illumination may be necessary from small portable banks of fluorescent lamps located at either side of the camera, in order that full length figures may be more uniformly lighted.

Modeling and highlighting can be accomplished by incandescent lamp spots of 500 to 1,000 watts rating. Some filtering with light-blue filters will be necessary to approximate the spectral quality of the fluorescent lamps.

Lighting of this character will increase personnel comfort and minimize the load on the studio air conditioning system.

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SECTION 15

MINIATURE LAMP APPLICATIONS

Miniature lamps are used most frequently when circumstances require that a light source be of small size or consume very little power. The various types, including miniature incandescent, glow, and fluorescent lamps, usually are listed in manufacturers' catalogs as miniature lamps.

About half of all miniature lamps manufactured are for use in automobiles. This application, which is standardized through the activities of the Society of Automotive Engineers, is described in Section 13.

Flashlights

There are several different types of flashlight lamps: the round-bulb, miniature-screw-base lamp; the prefocused lamp with flange-base; and the lamp with a lens in the end of the bulb. (See Table 15-1.) In addition to the standard types designed for use with dry cells, some flashlight lamps have been designed to be operated from small rechargeable storage-type cells which fit in the conventional flashlight, and others are designed with special filament ratings to match the characteristics of flashlights having built-in magneto-type generators. The capacity of such generators is lower than that of a battery, hence the light output of lamps designed for use with them is less than that of standard flashlight lamps designed for use with batteries.

Table 15-1. Sixteen Tungsten Incandescent Filament Lamp Designs in Common Use with Primary Batteries

LAMP NUMBER	RATED VOLTS	DESIGN VOLTS	DESIGN AMPERES	BULB SHAPE AND DIAMETER*	BASE†	BEAD COLOR	RATED AVE. LAB. LIFE (hours)	USED WITH FOLLOWING NUMBER AND TYPES OF BATTERIES‡
112	1.1	1.20	0.22	TL-3	min. sc.	pink	5	1—AA
131	1.3	1.30	.10	G-3½	min. sc.	white	50	1—D
222	2.2	2.25	.25	TL-3	min. sc.	white	5	2—AA
223	2.2	2.25	.25	FE-3¾	min. sc.	white	5	2—AA
233	2.3	2.33	.27	G-3½	min. sc.	purple	10	2—C
PR-4	2.3	2.33	.27	B-3½	s. c. min. fl.	lt. green	10	2—C
PR-2	2.4	2.38	.50	B-3½	s. c. min. fl.	blue	15	2—D
248	2.4	2.4	.8	G-5½	min. sc.	black	75	2—No. 6
35C	2.4	2.5	.8	G-5½	min. sc.	black	150	2—No. 6
PR-6	2.5	2.47	.30	B-3½	s. c. min. fl.	brown	15	2—D
14	2.5	2.47	.30	G-3½	min. sc.	blue	15	2—D
PR-3	3.6	3.57	.50	B-3½	s. c. min. fl.	green	15	3—D
PR-7	3.8	3.70	.30	B-3½	s. c. min. fl.	pink	15	3—D
13	3.8	3.70	.30	G-3½	min. sc.	green	15	3—D
502	5.0	5.10	.15	G-4½	min. sc.	blue	100	4—F
605	6.0	6.15	.50	G-4½	min. sc.	brown	15	5—D

* Letters indicate shape. Figures indicate diameter in eighths of an inch.
† min. sc. = miniature screw. s.c. min. fl. = single contact miniature flanged
‡ See Table 15-2 for cell dimensions.

NOTE: References are listed at the end of each section.

Lamp voltage. Battery voltage discharge curves, such as those shown in Fig. 15-1, determine the correct design voltage of lamps for use with different cells. The design voltage is the constant voltage which produces the same effect on lamp life as does the fluctuating voltage delivered by the battery.

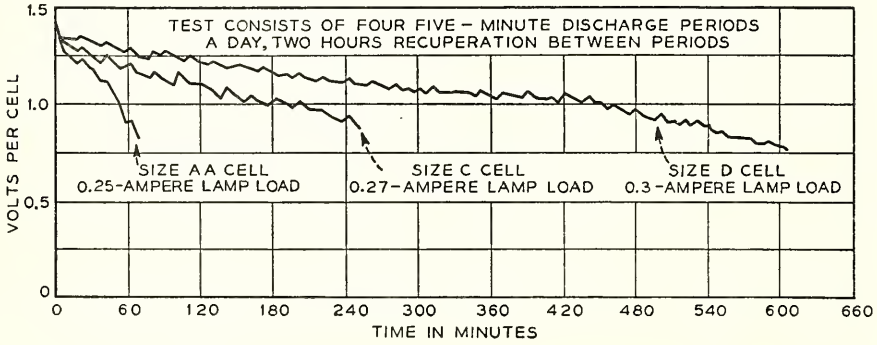


FIG. 15-1. Typical battery voltage discharge curves for several standard design primary dry batteries.

Lamp life. In addition to design voltage, design life also is important in a flashlight lamp. As a general rule the design life of a flashlight lamp is that which is most economical for producing light, taking into account the cost of battery power (which may be $15 per kilowatt hour or more), the cost of the flashlight, and the cost of the lamp. Today, the most economical life is about 15 hours for most standard types of flashlight lamps.

Light output and efficiency. The inherent efficiency of flashlight lamps varies considerably, depending on the lamp voltage. On lamps of very low voltage, such as one-cell lamps (1.25 volts) the losses caused by lead-wire cooling are very high and such lamps operate at 3.5 to 4 watts per spherical candle. Two-cell, 2.5-volt lamps have an efficiency of 1.5 watts per spherical candle; three-cell lamps, 1.15 watts per spherical candle; and four-cell, 5-volt lamps an efficiency of 1 watt per spherical candle. (To convert watts per spherical candle to lumens per watt, the term used to express the efficiency of most "large" lamps, divide 12.56, or 4π, by the watts per spherical candle rating.)

Flashlight batteries. The initial open circuit voltage of a common flashlight dry battery is approximately 1.5 volts per cell, regardless of its size. Usually this type is discarded when its voltage reaches approximately $\frac{3}{4}$ volt per cell. This 100 per cent voltage variation results in a light output six times greater on fresh cells than on nearly exhausted cells. There are three popular sizes of flashlight cells: the AA size cell, which is approximately $\frac{1}{2}$ inch in diameter and $1\frac{7}{8}$ inches long; the C size cell, which is $\frac{15}{16}$ inch in diameter and $1\frac{13}{16}$ inches long; and the most popular D size cell, which is $1\frac{1}{4}$ inches in diameter and $2\frac{1}{4}$ inches long. (See Table 15-2.) All sizes have different ampere-hour capacities and different voltage discharge curves.

Table 15-2. Ten American Standard Sizes of Dry Cells*

DESIGNATION	NOMINAL CELL DIMENSIONS	
	Diameter	Height
AA	$\frac{1}{2}$ in. (12.7 mm)	$1\frac{7}{8}$ in. (47.6 mm)
A	$\frac{5}{8}$ in. (15.9 mm)	$1\frac{7}{8}$ in. (47.6 mm)
B	$\frac{3}{4}$ in. (19.1 mm)	$2\frac{1}{8}$ in. (54.0 mm)
C	$\frac{15}{16}$ in. (23.8 mm)	$1\frac{13}{16}$ in. (46.0 mm)
CD	1 in. (25.4 mm)	$3\frac{3}{16}$ in. (81.0 mm)
D	$1\frac{1}{4}$ in. (31.8 mm)	$2\frac{1}{4}$ in. (57.2 mm)
E	$1\frac{1}{4}$ in. (31.8 mm)	$2\frac{7}{8}$ in. (73.0 mm)
F	$1\frac{1}{4}$ in. (31.8 mm)	$3\frac{7}{16}$ in. (87.3 mm)
G	$1\frac{1}{4}$ in. (31.8 mm)	4 in. (101.6 mm)
No. 6	$2\frac{1}{2}$ in. (63.5 mm)	6 in. (152.4 mm)

*American Standard Specification for Dry Cells and Batteries, National Bureau of Standards, Washington, D. C.

Flashlight reflectors. The most popular flashlights are the spotlight type employing parabolic reflectors ($1\frac{1}{2}$ to $1\frac{3}{4}$ inches diameter and $\frac{1}{4}$ inch focal length) and prefocused types of lamps. When a beam from a flashlight of this type is projected on a wall at a distance of 30 feet the spot produced consists of a multiplicity of filament images that have been magnified approximately 1,000 times. To ensure uniform small round spots, the reflector contour must be accurate. If it were not for that light which, emanating direct from the filament, does not strike the reflector, the spotlight type of flashlight would not be very useful for most purposes, since by itself the beam is too concentrated. A diffusing element which may be introduced or removed at will by a flashlight user sometimes is included to overcome this difficulty. *Bull's-eye* type flashlights produce a beam of a much lower candlepower which approximately fills a 60-degree cone.

Appliances

Miniature lamps are used on various appliances primarily as indicators to show visually that power is flowing to the device, or that it is functioning properly.

Flat irons. Low-voltage, tungsten-filament lamps have been employed by connecting them in series-shunt arrangement as shown in Fig. 15-2*a*, to indicate whether the heater element is in or out of the circuit. When the thermostat opens, the lamp goes out. The lamp must be located where it will not get too hot. Base solder will melt and basing cement will loosen at 300 degrees Fahrenheit.

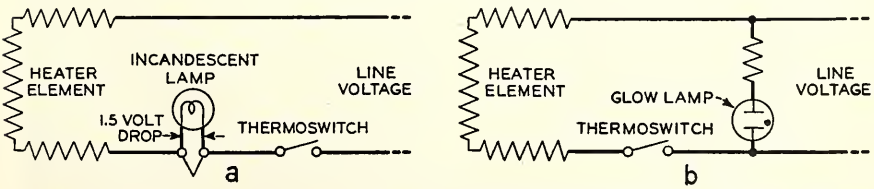


FIG. 15-2. Typical circuits used in flat irons, toasters, electric blankets, and other heating appliances. a. Series-shunt type for incandescent lamps. b. Shunt type for glow lamps.

T-2 or T-3¼ bulb glow lamps also are used widely for this purpose. Generally, these are located in an iron handle to remove them from the heat. They are connected to the power supply through a resistor as shown in Fig. 15-2*b*, and so are not affected by the action of the thermostat. Glow lamp electrodes should be viewed directly for best results; except when they are to be used in dark surroundings, as at night, their brightness is too low to permit the use of a cover plate of any sort.

Waffle irons, toasters, and other heating appliances. The series-shunt arrangement used in flat irons (Fig. 15-2*a*) seems most suitable for waffle irons as it indicates that a waffle is cooked when it goes out with the opening of the thermostat.

Either circuit shown in Fig. 15-2 may be used for toasters, percolators, curling irons, soldering irons, etc. Heating pad and electric blanket circuits usually incorporate glow lamps in a control switch as it is desirable to be able to tell at a glance that a blanket is operating, even though a thermostat may have opened the power circuit temporarily.

Ranges. Low-voltage miniature lamps are used as oven indicators in electric ranges. Lamps are connected in a series-shunt circuit. One-hundred-twenty volt lamps are used in top-burner circuits. The 6-watt S-6 and 7-watt C-7 lamps used are about the smallest 120-volt incandescent lamps it is practical to make. Their small diameter filaments are very fragile.

Home freezers. In a home freezer circuit a visible pilot light should indicate that the freezer is functioning properly. It is recommended, for this purpose, that a sturdy, low-voltage, long-life lamp of the radio-panel type be used. It should be operated at a reduced voltage to prolong its life.

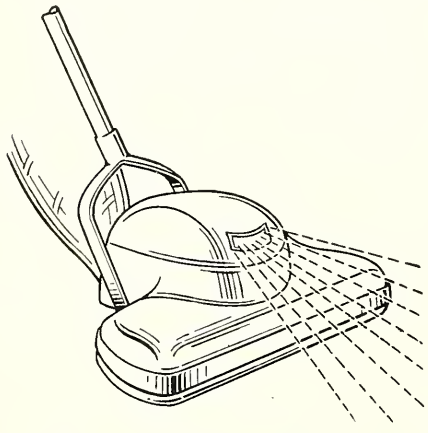


FIG. 15-3. Typical lighted vacuum-cleaner.

Vacuum cleaners and sewing machines. The small 120-volt lamps used on these devices provide local lighting that assists in their operation. (See Fig. 15-3.) The most common vacuum-cleaner lamp is rated 25-watts at 120 volts and has a T-8 bulb and a double-contact bayonet base. The greater light output of a 50-watt T-8 bulb lamp can be utilized to increase operator efficiency. The filament construction of both vacuum-cleaner and sewing-machine lamps prevents adjacent filament coils from short-circuiting from shock, and the type of filament wire used resists vibration.

Sewing machines use a 15-watt, 120-volt, T-7 frosted-bulb lamp with a double-contact base, as shown in Fig. 15-4. Higher wattages are not used as they cause higher bulb temperatures than can be tolerated. Two small 4-watt, 6-inch fluorescent lamps mounted one on either side of the sewing-machine head provide proper illumination without a hot bulb hazard.

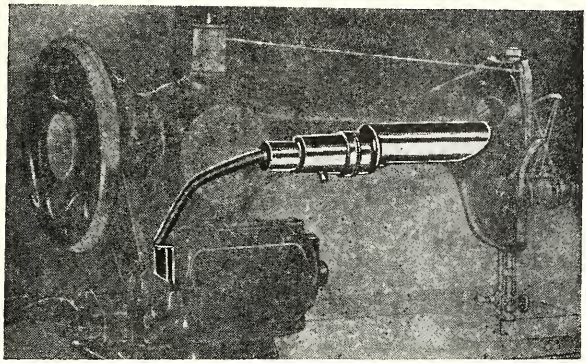


FIG. 15-4. Typical household-sewing-machine lamp.

Clocks. Electric clock faces can be illuminated with miniature lamps. A T-3¼ bulb lamp drawing 0.5 ampere at 2.5 volts, with a miniature base, is suitable for small clocks. An extra coil on the motor winding can be used to provide the proper voltage. Two methods of lighting clock dials have been found effective and a third has been suggested:

1. A translucent dial may be used in front of a diffusing cavity of approximately ½ inch depth. The interior of this cavity is coated white and includes the filament end of the lamp. A shield keeps direct light from the dial, which therefore is diffusely illuminated. (See Fig. 15-5*a*.)

2. Edge lighting provided by a lamp located at the focal point of a parabolic bottom section of the dial also is used. The entire edge of a glass or plastic dial is silvered and numerals are etched or painted on the surface. A step in the dial or a second parabolic section projects light across the background of the dial to illuminate the hands, which should be beveled to collect the projected light and diffuse it forward.

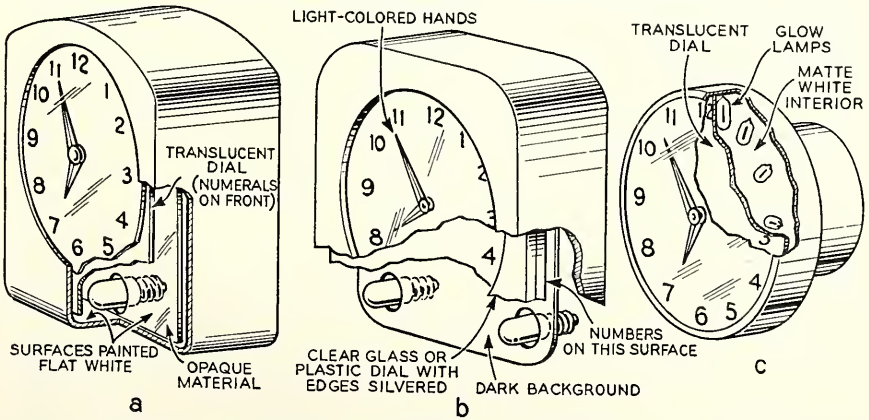


FIG. 15-5. Designs for illuminated clock dials. a. Translucent dial in front of illuminated diffusing cavity. b. Edge lighted dial and hands. c. Glow lamp pattern.

3. It has been suggested that twelve 0.04-watt glow lamps, one located at each hour position, would illuminate a background against which the hands could be seen in silhouette. (See Fig. 15-5*c*.)

Indicator Panels, Annunciators, and Switchboards

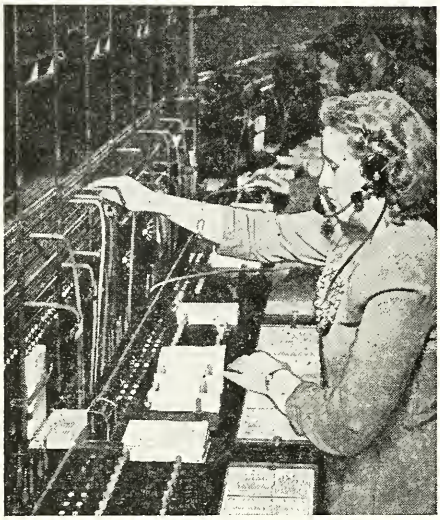


FIG. 15-6. Telephone switchboard panel. Lighted lamps indicate condition of circuits.

Telephone switchboard. The T-2 bulb, slide-base lamps, commonly known as telephone switchboard lamps, are used for a variety of purposes in a telephone switchboard. (See Fig. 15-6.) In most instances the lamp functions in conjunction with other pieces of equipment and hence its design is controlled by the circuit characteristics. These lamps are made with ratings in the range from 4 to 60 volts and in several different current ranges. Usually they are used behind small glass jewels or printed paper strips. Lamp characteristics are fixed by the original design of the board, and it appears that improved jewels and paper tape offer the greatest potential for immediate increases in signal brightness.

Elevator annunciator. Many elevators in large buildings use miniature lamps not only in the car to indicate its position but on a supervisory board in the lobby, to aid the starter. These lamps are made with T-3 bulbs, and have a miniature screw base and a rating from 10 to 32 volts. The 14-, 18-, and 24-volt, 0.17-ampere lamps are the most common.

Hospital annunciator. A low-voltage call system is used in many large hospitals. Voltages between 6 and 36 volts are encountered, though 24 volts is standard for new installations. Most lamps used on these circuits have a G-6 bulb and a candelabra screw base or single-contact-bayonet candelabra base.

Tools and Instruments

Tools. Many kinds of miniature lamps are employed in industry. Some are used as inspection lights for small cavities. The T-1$\frac{3}{4}$ bulb, midget-screw-base lamps are suitable for extremely small inspection lights. They are available with 2.5- and 6-volt ratings. These lamps are less than $\frac{1}{4}$ inch in diameter, and are mechanically strong. Others are used to test the potential or continuity of circuits and (on d-c circuits) glow lamps indicate polarity. They may be incorporated in screw drivers, plumb bobs, or wrenches. A 1-candlepower lamp provides an illumination level of more than 100 footcandles on surfaces 1 inch from the filament.

Illuminated indicators of various kinds are much more conspicuous than those depending upon reflected light only and often are more compact. Flashlight batteries and flashlight lamps are used frequently; but, where a lamp is operated continuously, radio-set, filament-heating transformers may be used instead of batteries.

Neon glow lamps are used widely for testing circuits on 110 to 120 volts. Low-voltage circuit testers usually employ T-2 bulb, tungsten-filament lamps of the telephone-switchboard type.

Instruments. Miniature lamps can be used to illuminate panel-type meter dials so as to overcome the shielding effect of light externally reflected by the cover glass. A lamp centered inside the case also can be used.

Many *microscopes* require local illumination. Some use small 120-volt lamps in a separate condenser type of illuminator. In others, miniature lamps are built into illuminators attached to the microscope. Low-voltage microscope lamps employ a filament that approximates a square in cross section. They are available with ratings of 6.5, 8, and 11.5 volts and with bayonet and miniature screw bases. Such a source with a closely wound filament is capable of producing a high illumination level on the small specimen area being examined. A few microscope illuminator lamps have been made with ring-type bulbs; one such lamp is approximately $1\frac{1}{2}$ inches in diameter and another $2\frac{1}{2}$ inches. These lamps are equipped with wire terminals. Because construction is difficult and few are made they are more expensive than the more common types.

Miniature lamps, such as one with a G-10 bulb and a candelabra-screw base, having an S-6 straight wire filament, and rated at 3 to 4 volts and 0.5 ampere, are used in *galvanometers.* For lamps of this character as well as for *oscillograph* and *seismograph* lamps, bulbs are individually selected for freedom of minute glass imperfections. Not all oscillograph lamps employ straight wire filaments, a few use coiled filaments. Some of these lamps employ a spring to keep the filament straight.

Pinball Games and Juke Boxes

Pinball games. A variety of miniature lamps in the voltage range between 6 and 28 volts has been used in pinball games. Many games incorporate seventy-five or more lamps. In order to simplify the wiring it is desirable that the lamps have filaments of 25 to 28 volts, since that voltage range operates the relays also incorporated in these games.

Phonographs or juke boxes. Coin-operated phonographs (juke boxes) frequently utilize miniature lamps for decorative effects. These are employed principally because of their small size, low price, and rugged structure. They are operated from a transformer. A 6- to 8-volt lamp in a G-6 bulb with a single-contact bayonet base is used frequently. Its rated output is 3 candlepower and it has a life of 1,000 hours. Fifteen-watt white and colored fluorescent lamps also are being used to illuminate the large translucent plastic panels often incorporated in these machines. The latter produce more lumens per watt than incandescent lamps. This is advantageous since heat emitted by decorative lamps and by tubes in the amplifier circuit must be limited.

Radios

Early a-c–d-c radios without filament transformers used a 6.3-volt, 0.15-ampere lamp shunted by a resistance of about 30 ohms. (See Fig 15-7.) This was not a satisfactory circuit. Though the initial current surge caused early lamp failures, the operating voltage was so low that lamps emitted very little light. Because of the relatively long time required for radio tube filaments to warm up (during which time the current may be several times normal), a lamp of the same current rating as the tube filament cannot be operated in series as it will warm up rapidly and burn out.

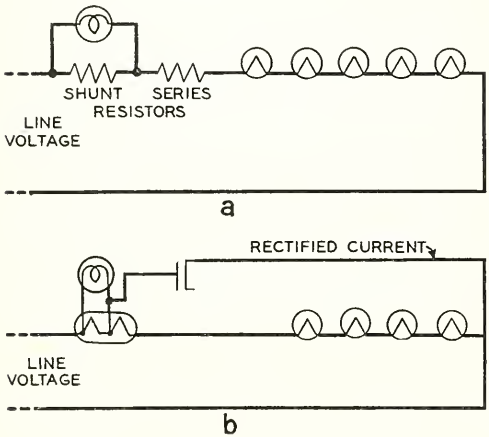


FIG. 15-7. Alternating and direct-current radio-tube-filament and panel-lamp circuits. a. Early fixed resistance lamp shunt design; b. Improved circuit utilizing a tube filament for shunt resistance.

Later models utilizing 35Z5 and similar radio tubes are provided with the same type of lamp but the lamp's filament is shunted by a section of the tube's filament. (See Fig. 15-7.) This protects the lamp during the initial current surge. Then, as the radio tubes warm up, the rectified power begins to flow and this also passes through the lamp and its parallel radio-tube-filament section. On this circuit the lamp operates near rated voltage and emits adequate light. Small 120-volt lamps are not as strong as 6- to 8-volt panel lamps and may cause the set to be noisy. Noise is a result of a vibration-induced filament movement that causes intermittent shorting of a few turns. If an unshielded lamp is in close proximity to a loop aerial, radiation resulting in noise may be picked up.

Both a 10-watt, 120-volt, C-7 bulb special radio-panel lamp and the standard 120-volt, 7-watt, C-7 bulb lamp have been used in a few sets, though shock and vibration reduce their useful life.

Vibration. The sound vibrations of audible frequencies are impressed on the pilot and dial light incorporated in radio-receiving sets. The frequencies range from less than 100 cycles to several thousand cycles per second. Like other objects, the mount structure and filament coil have their own critical resonant frequencies. It is necessary to protect the filament from destruction by vibration and it has been found possible to design mount and filament structure to synchronize their resonant frequencies approximately, so that they respond in unison. This design improves the vibration resistance characteristic of a lamp and in addition increases its resistance to shock also. It has been found also that, under

the influence of vibration, the resistance of the joint between the filament leg and the lead-in wire can change enough to produce radio interference in a radio set if the clamp is not tight.

Glow lamps also are used in radio sets. One Neon glow lamp, with a T-4½ bulb and a double-contact bayonet base, draws 0.002 ampere at 105 to 125 volts and has characteristics that permit its use as a voltage regulator in some receiver circuits.

A similar lamp has been used to indicate the output voltage of a B battery. The lamp is connected in a relaxation circuit with a 4-megohm resistor in series with the lamp and a 0.1-microfarad condenser across the lamp. (See Fig. 15-8.) In such a circuit, as the battery voltage drops the flash rate is reduced thus giving a visual indication of the battery conditions. The drain on the batteries caused by the lamp is negligible.

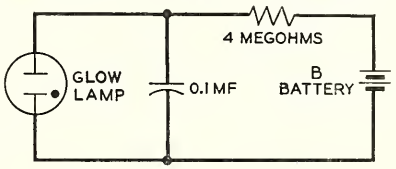


FIG. 15-8. The flash frequency of a glow lamp in a relaxation circuit is directly related to the impressed voltage.

Toys and Bicycles

Toy trains. Lamps with miniature screw bases and a rated life of 250 hours are used most commonly in toy trains. They are made with G-4½ or G-3½ bulbs for operation at 12, 14, and 18 volts. A few lamps have been made with special bulbs resembling street lights and these have been used also on toy station platforms. For the scale model HO gauge trains, 6-, 12-, and 18-volt lamps with midget screw bases are available.

Doll houses and other toys. The preferred method of lighting doll houses is to connect 6-volt T-1¾ midget screw-base lamps to a 6-volt, radio-tube-filament transformer. Slightly larger lamps with G-3½ or T-3¼ bulbs or even small automobile tail lamps also can be used. Multiple wiring is an advantage as ordinary bell wire is sufficiently insulated for the purpose.

For small wheeled toys requiring two lamps, a 2.4-volt lamp drawing 0.22 ampere within an FE-3¾ bulb is suitable. It employs a shallow, flat end, enameled back bulb and has a current rating which should provide long battery life even if two lamps are operated on two standard size D cells.

Bicycles. Bicycle lamps should have a low watt rating in order that the batteries on which they are operated may have a practical life. A 1.3-volt, 0.1-ampere lamp with a G-3½ bulb and a miniature screw base is suggested for bicycle taillights. A standard size D cell may be expected to operate one of these lamps 20 to 25 hours. A taillight is considered more essential than a headlight, though most bicycles which have only one use a headlight. Many state laws pertaining to the subject specify the distance the bicycle taillight is to be visible rather than an exact candlepower and beam distribution.

Three watts is about the maximum load that can be added to the bicycle without appreciably increasing the difficulty of pedaling.

Surgical Instruments

In 1926 an investigation was made of the lighting requirements of this field.* Over 100 different types of lamps were found in use.

Many of the lamps used in this field differ from one another only slightly in base threads per inch, electrical rating, filament form, etc. If a serious attempt were made to standardize these lamps, the number of types manufactured could be reduced. Such standardization usually is accompanied by improved quality and lower costs.

The various lighted instruments were classified* in five groups as follows: (See Fig. 15-9.)

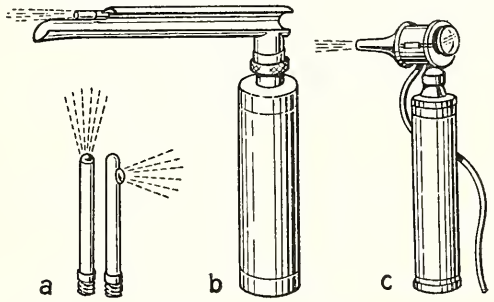


FIG. 15-9. Typical lighted diagnostic instruments for: a. Transilluminator lamps; b. The throat, lungs, and rectum; c. The nose and ears.

1. *Throat, lungs, and rectum.* These devices do not require an extremely white light. The walls of the organs into which the instruments are passed close over the end of the instrument, thus placing the diseased tissue within close range of the lamp. The usual procedure is to operate the lamps with their filaments "just off the yellow."

2. *Genitourinary organs.* Because of the extremely small passages through which these instruments must pass, direct vision of the infected area is impossible, and an optical viewing system of very small lenses is used. The cavities at the far end of these passages, the bladder, for instance, must be inflated with a liquid which frequently is rendered foggy by body secretions. In order to see the opposite bladder wall through the lens system and foggy liquid, a high-candlepower white light is required.

3. *Eyes (ocular).* In these instruments both yellow and white light may be utilized to advantage. For instance, in ophthalmoscopy, particularly when it is necessary to view the choroid tissue through the retina by means of a "red free" screen, a high-candlepower white light is necessary. However, in retinoscopy, light of a yellowish color can be used.

4. *Nose and ears.* Instruments for nose and ear examination utilize diffuse white light.

5. *Transillumination.* For transillumination, high candlepower and white color is recommended.

In preparing for surgery the operating-room nurse, after laying out the instruments, adjusts the lamp visually to approximate the brightness desired by the surgeon, so that it will be ready for immediate use.

* Porter, L. C., "Standardization of Surgical and Dental Lamps," *Edison News Letter*, July, 1926. Porter, L. C., and Roy, A. C., "Ten Lamps or 118," *American Surgical Trade Association Journal*, January, 1926.

SECTION 16

MISCELLANEOUS APPLICATIONS OF RADIANT ENERGY

In addition to the wide variety of uses of light as an aid to seeing, which are described in other sections, there are many applications and effects of light and of ultraviolet and infrared energy also, in which seeing, if it is involved at all, is of minor importance. These include:

Light	Photoelectric control Aiding photosynthesis and production of chlorophyll, (plant growth) Fading of colored materials Insect attraction and trapping
Ultraviolet	Development of erythema Production of vitamin D Prevention and cure of rickets Poultry raising Photochemical actions Catalysis of chemical reactions Microorganism growth control as in air and liquid sterilization
Infrared	Radiant heating and heat therapy Production drying, softening, heating Dehydration

Radiant-Energy Sources

Many of the light sources described in Section 6 produce small quantities of ultraviolet energy (wavelength less than 0.38 micron) and infrared energy (wavelength more than 0.76 micron) as well as light energy. In most cases, the amount of ultraviolet energy emitted by sources used for general lighting is not of practical importance. However, 75 per cent or more of the output of standard incandescent-filament lamps, including those with high ratings of 20 to 30 lumens per watt, is emitted in the infrared spectral region. Filament lamps designed as infrared emitters may produce 90 per cent or more of their output in the infrared wavelengths.

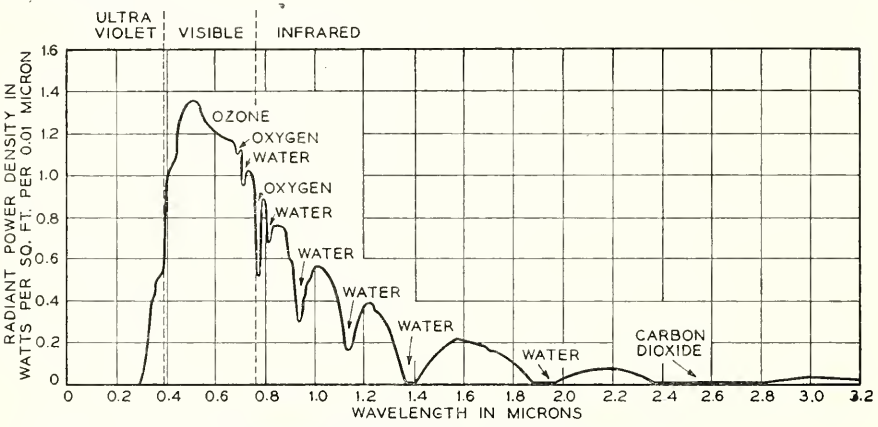
The production of ultraviolet and infrared energy may be accomplished in much the same manner as the production of light, as explained in Section 1. The principles of light control described in Section 7 are equally valid in most cases for infrared and ultraviolet energy as well.

Figure 16-1 shows the characteristics of solar energy at the earth's surface.

NOTE: References are listed at the end of each section.

Reflectance, Transmittance, and Absorptance of Radiant Energy

Ultraviolet and infrared radiant energy conform to the same laws of physical optics as light energy and are, in fact, similar, in all respects except wavelength, to light that itself is radiant energy evaluated with respect to its capacity to produce visual sensation in human observers. As indicated in Section 2, the normal human eye, though blind (from the standpoint of ordinary seeing tasks) to radiation of wavelengths shorter than 0.38 micron, or longer than 0.76 micron, does react slightly to these "extra-visual" wavelengths. Other radiant-energy-sensitive receptors also, such as photoelectric cells and some chemical compounds, exhibit individually characteristic response curves which may have peaks in the ultraviolet, visible, or infrared regions. (See Fig. 16-2.) The reflectance and the transmittance characteristics of materials vary with wavelength also. (See Table 16-1.)

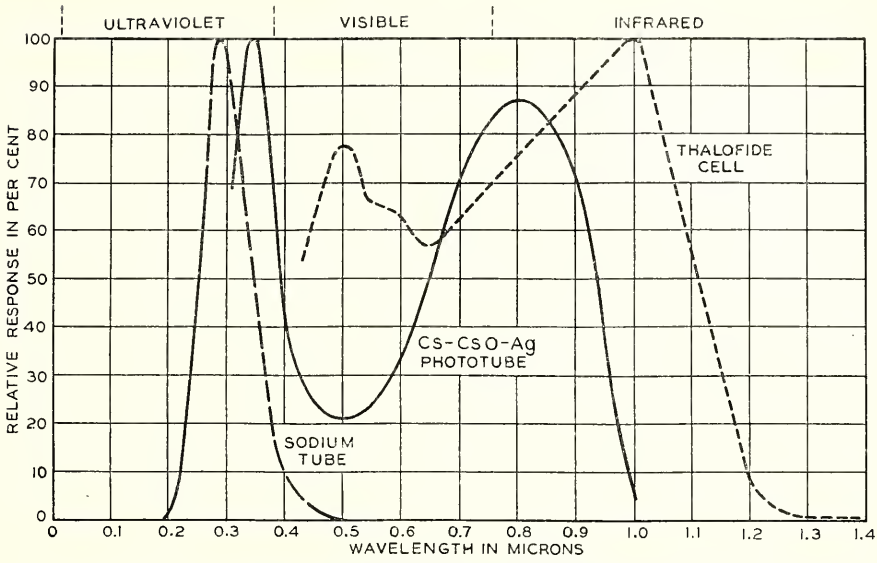


1 micron = 10,000 Angstroms = 1/10,000 centimeter

FIG. 16-1. Spectral distribution of solar radiant power density at sea level, showing the ozone, oxygen, water, and carbon dioxide absorption bands.

Table 16-1. Reflectance of Various Materials for Energy of Wavelengths in the Region of 0.2537 Micron

MATERIAL	REFLECTANCE (per cent)
Aluminum	
Untreated surface	40–60
Treated surface	60–89
Sputtered on glass	75–85
Paints	55–75
Stainless steel	25–30
Tin plate	25–30
Magnesium oxide	75–88
Calcium carbonate	70–80
New plaster	55–60
White baked enamels	5–10
White oil paints	5–10
White water paints	10–35
Zinc oxide paints	4–5



1 micron = 10,000 Angstroms = 1/10,000 centimeter

FIG. 16-2. Relative response of several sensitive elements to energy of different wavelengths.[2]

MISCELLANEOUS APPLICATIONS OF LIGHT

Automatic Control with Photoelectric-Cell-Operated Relays

A number of energy-beam, photocell-operated relay applications have been developed.[3] Typical of the common uses are door opening and closing, burglar alarm operation, safety shutoff of hazardous machinery, conveyor control, production-unit counting, and production-quality control. In schoolrooms photocell control of electrical illumination has been used.

A light, ultraviolet, or infrared energy beam and photocell combination may be arranged in such a manner that action takes place either upon incidence of the beam on the cell or upon interception of the beam and darkening of the cell. Typical installations are shown in Fig. 16-3

Use of Light in Horticulture[4]

The growth of plants is a complicated process. Roots absorb water and mineral salts from soil. A stem carries these materials to leaves and blossoms. Leaves extract carbon dioxide from the air. With the aid of a green pigment known as chlorophyll, carbon dioxide has the ability to absorb light energy which, combining with water and mineral salts taken from soil by roots, forms the sugars and the starches needed for plant life. The process is known as photosynthesis. During the process a leaf breathes in carbon dioxide, retains carbon in carbohydrates, and liberates oxygen.

The time of bloom of most plants is determined primarily by the total number of hours of light received in each 24-hour day.

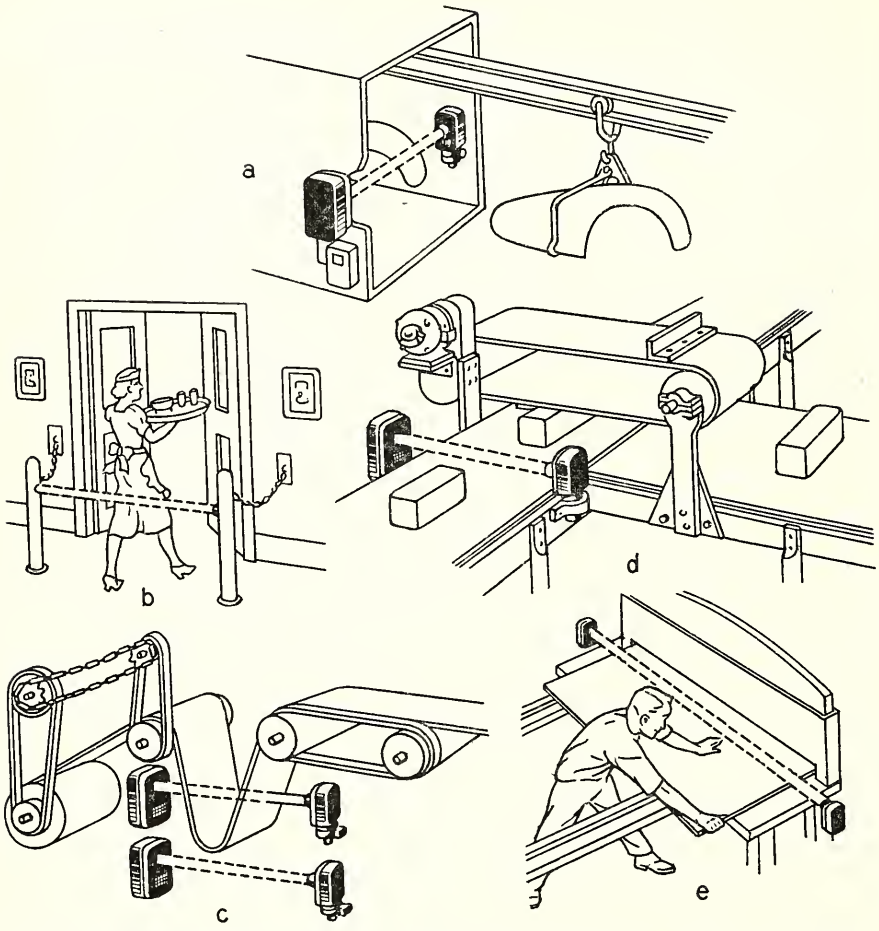


FIG. 16-3. Typical applications of photoelectric-cell-operated relays: (a) Light source and photocell-operated relay arranged as an automatic counter. (b) Photocell-operated relay controls door-opening mechanism. Photocell-operated relays may be used (c) To operate limit switches; (d) To sort objects of different sizes; or (e) To operate safety shutoff switches.

If it is desired to force the long-day plants, that is, have them bloom early so as to get them onto a favorable market, it can be done by extending the daylight hours with electrical illumination. Many plants respond well to a level of 15 footcandles, some to as low as 2 footcandles. Some, such as roses and orchids, require considerably more (several hundred footcandles) illumination. (See Fig. 16-4.)

Conversely, some of the short-day plants, notably chrysanthemums, will have their time of bloom retarded by extending the natural daylight period with electrical illumination. This method has been used to encourage chrysanthemums to bloom at Christmas time instead of in October.



FIG. 16-4. Effect of increasing the hours of light on "long-day blooming" plants: a. Scabiosa on right bloomed in 172 days as a result of supplementing daylight with electrical illumination. b. Orchids without and with 5 weeks of supplemental illumination (135 footcandles).

Some investigators believe that when electrical illumination is used for forcing or stimulating plant growth there should be a continuous day of natural and artificial light for the plants. They report that light applied in the middle of the night for a few hours does not seem to produce the effects gained when the natural and artificial light combine to make one continuous period.

Some long-day plants will flower on any length of day from 12 to 24 hours. However, most plants will flower on 16 to 18 hours of light but will not flower if lighted continuously for longer periods. On this basis some plants have been made to grow for years without a blossom, and have flowered when they were put on a reduced-light diet.

The period in the development of plants in which the application of electric light is most effective varies considerably with the plant. Some require light throughout life and others during early stages only. In general, earlier flowering is brought about by lighting during the first half of the life of the plant. Lighting during the later stage, although it usually increases stem length materially, has less influence on the date and increase of flowering, though often it is effective in opening flower buds quickly.

Lengthening the total lighted period to get early bloom can be successfully accomplished at relatively low illumination levels. The provision of 5 to 15 footcandles may be commercially profitable. However, this practice is most likely to succeed where strong healthy plants are used and where there is an abundance of sunlight during the day. The use of low levels of electrical illumination on weak plants or as a substitute for sunlight is likely to be a complete failure.

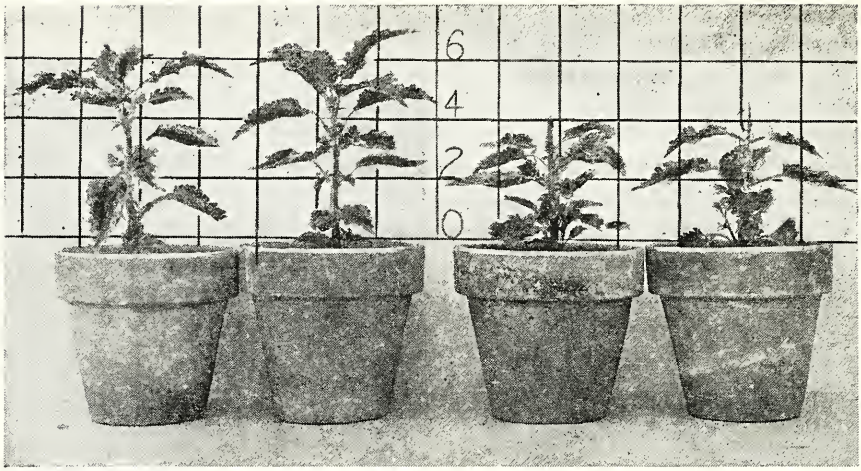


FIG. 16-5. Effect of radiant energy from an ultraviolet source on *Coleus* plants.[4] Irradiated plants are at the right, control plants at the left.

As shown in Fig. 16-5 exposure to high density short-wavelength, ultraviolet-energy is likely to inhibit plant growth. Though not injurious, infrared energy is not always required.

Various experiments have been conducted to determine the feasibility of forcing vegetables with light. There is no difficulty in increasing growth but the likelihood of doing so at a profit is less with vegetables than with flowers.

Where tomato seedlings are lighted bud drop is reduced and the final weight of tomatoes harvested increased.

Fading and Bleaching

Fading. It has been determined that the fading or discoloration of dyed fabrics, paints, and transient pigments or compounds is a function, primarily, of the exposure duration $\times$ the radiant energy intensity. Thus footcandle-hours roughly measure the probable fading unless extreme conditions exist.[5,6,7,8]

Many variables such as heat, wavelength of radiant energy, humidity, purity of air, and chemical and physical nature of coloring matter and of containing surface must be considered as influencing the rate or degree of fading attributed to all qualities of artificial and natural light.

A summary of the general relationships may be stated as follows:

1. The fading of a colored textile and probably of plastics and similar materials is approximately proportional to footcandle-hours for any particular light source. Either the incident illumination or the exposure time may be varied over a moderate range, provided the product of these two factors is unchanged.

2. Atmospheric humidity has little influence on the rate of fading although some gases may mix their bleaching action with that of radiant energy.

3. Between temperatures of 85 to 120 degrees Farenheit there is very little difference in fading rate. Higher temperatures may increase it.

4. Most of the fading produced by natural daylight appears to be caused by energy of wavelengths shorter than approximately 0.6 micron.

5. Most colored fabrics are particularly susceptible to short-wave ultraviolet energy. The fading rate when exposed to 0.2537-micron energy may be very much faster than when exposed to the same radiant power density of light of mid-spectrum quality.

6. Reasonably good quality materials show no disturbing fading upon exposure to incandescent illumination up to some 50,000 footcandle-hours.

For equal fading, and if equated on average relative exposures in footcandle-hours, the following relative fading rates seem to represent average results with colored textiles:

1.00 for natural daylight (6,000 degrees Kelvin)

0.55 for tungsten-filament lamps (2,850 degrees Kelvin)

0.60 for daylight fluorescent lamps (6,500 degrees Kelvin)

Thus, nearly all dyed textiles may be exposed safely to natural daylight for about 30,000 footcandle-hours. In practice, in an average show window with illumination on the goods of 275 footcandles, the safe exposure would be about 100 hours or roughly 8 days.

Bleaching. Illuminants, such as the carbon arc, that roughly duplicate the qualities of sunlight are used to test the fastness of dyes. Either these illuminants or those emitting energy of 0.2537-micron wavelength are employed to bleach linens, waxes, straws, and some food products. The spectral change that occurs in a normal fading process increases slightly the reflectance in regions of maximum absorption and causes a decrease in reflectance in regions of minimum absorption.

Light for Insect Trapping[9]

Light sources are used in agriculture as lures for phototropic insects, particularly to control the codling moth, fruit flies, and night-feeding beetles. General conclusions have been reached as follows:

1. The closer light wavelengths approach the blue end of the spectrum, the more insects they attract.

2. The closer light wavelengths approach the red end of the spectrum, the fewer insects they attract.

3. The higher the brightness of a source, the greater its attraction power, regardless of color.

4. The substitution of yellow lamps for white lamps of equal candlepower reduces the number of insects attracted by approximately 50 per cent.

5. Because bare lamps attract insects from all directions and only a small percentage of the light emitted by a bare lamp falls on the area it is desired to light, they attract more insects than lamps in reflectors.

6. The use of reflectors and regular inside-frosted lamps will reduce the number of insects attracted.

7. The use of projector or reflector spotlight-type bulbs results in the maximum reduction of insects when the sources are located 20 or more feet away from the area it is desired to illuminate.

8. The addition of opal diffusing globes or other means of reducing bare lamp brightness will reduce the numbers of insects attracted.

In outdoor lighting the probable brightness of areas illuminated to a level of less than 100 footcandles will not attract phototropic insects to any degree comparable to the attraction of an exposed source. Bright sources should be placed at considerable distances from lighted areas if insects are a nuisance near the area, or such sources should be well shielded with reflectors and louvers.

In applying these conclusions, the principles of good lighting for vision described in the preceding sections of this handbook should be followed.

To reduce insect density around outdoor swimming pools, underwater lighting is recommended. Fish hatcheries can attract insects to pools by operating high brightness lamps over or near the pools.

Luminescent Materials—Fluorescent, Phosphorescent, Radium-Luminous

Fluorescent, phosphorescent, and radium-luminous materials found many and varied military uses during World War II. Almost nonexistent prior to the war, many of these materials are now available in quantity for commercial application.

Luminescent means *emitting light for reasons other than that of being heated to incandescence.* A firefly's tail-light and the phosphors in a fluorescent lamp or a watch dial that glow in the dark are luminescent. The electric filament lamp is not, it is incandescent. Luminescent materials might be defined, loosely, as "cool" producers of light. The subdivisions of luminescence, which are numerous, are exemplified by the following (also discussed in Section 1):

Photoluminescence. Light resulting from light absorption.

Triboluminescence. Light resulting from mechanical friction.

Chemiluminescence. Light resulting from chemical combination.

Cathodoluminescence. Light resulting from bombardment by electrons.

Thermoluminescence. Light resulting from thermal changes.

Of these, one of the most easily demonstrated is triboluminescence. The sudden stripping of friction or adhesive tape from a roll in a dark room will result in a noticeable light emission along the edge of separation between the tape and the roll.

The three types of luminescence that are now available for practical application are fluorescence, phosphorescence, and radioluminescence.

Materials that emit light when irradiated with ultraviolet energy are termed fluorescent. There are two types of fluorescent materials: those depending for fluorescence on organic dyes, and those compounded from inorganic alkaline earth salts. Dependent upon the methods and ingredients used in manufacturing the inorganic compounds, the process of

light emission may cease immediately upon cessation of the exposure, or it may continue for an indefinite period. The property of continuing to emit light after the energizing source has been removed is known as phosphorescence. Certain of the alkaline earth sulphides exhibit this property for a significant period of time after the activating exposure ceases and for this reason are classed as phosphorescent materials.

Phosphorescent materials are activated not only by ultraviolet energy but also by light. (Most fluorescent materials respond also to light wavelengths, but because of the masking effect of the reflected light the relatively small fluorescent brightness component is not noticed.) Many alkaline earth sulphides not only emit light when exposed to ultraviolet or light energy, but also exhibit this property under bombardment by alpha rays from radium. Thus, by compounding a mixture of such a radioluminescent material and a small amount of radium compound, a self-luminous mixture can be produced. Such a radium-luminous compound will continue to emit light without the help of external activation of any type for periods as long as six months to a year in practical applications.

Fluorescent materials. Most fluorescent materials now available commercially depend upon organic dyes as the source of their fluorescence. Used in night clubs, theaters, ice shows, and other places of entertainment, these materials form spectacular displays when excited by ultraviolet energy in a darkened area. Practically all of the fluorescent materials used commercially today are activated by ultraviolet energy of the 0.3650-micron wavelength. This wavelength is emitted by mercury-vapor lamps filtered with a type of glass that absorbs the greater part of visible light but permits the relatively invisible ultraviolet radiation to pass through.

The 360 BL fluorescent lamp has a high percentage of its output in the 0.3650-micron region and can be used in combination with the proper filter for exciting fluorescent materials. However, this source is not as concentrated as the mercury-vapor-discharge lamp, and where more precise control of the radiation is necessary, the mercury lamp is preferred. Argon-glow lamps furnish ultraviolet energy of the proper wavelength for exciting fluorescence, but in small quantities. Incandescent-filament lamps, though they emit a small amount of near-visible ultraviolet, are quite inefficient sources. In order to transmit a useful amount of ultraviolet, any filter used with filament lamps must pass a large amount of light also. This masks the fluorescent effect.

Fluorescent paint, ink, and dyed fabrics are available in many colors, including red, orange, green, blue, yellow, and a white that appears blue under ultraviolet. Because these materials transform ultraviolet energy into light, as well as reflect incident light, their brightness under daylight is striking. This is true because of the ultraviolet energy in daylight, which, after striking the material, returns to the eye as light in addition to the daylight reflected by the material and gives some fluorescent materials an *apparent reflectance* (under daylight) as great as 110 per cent, that is, they send back more visible light than strikes them. This quality is especially useful in signal flags and signal panels that can be seen at greater distances

than those with nonfluorescent surfaces. The increased range over which the fluorescent flags can can be seen is most apparent during the half-light conditions of dawn and twilight.

This phenomenon is commercially applicable wherever the long distance visibility of objects is important throughout the hours of daylight. Where twenty or thirty small private airplanes may be flying from one field, visibility of each plane can be noticeably improved through the use of high-daytime-reflectance fluorescent paint.

At night, the decorative possibilities and combinations obtainable through the use of fluorescent cloth or paint under ultraviolet energy are limitless. Red or orange-red dials, numbered in fluorescent paint and irradiated with ultraviolet energy, cause less interruption of dark adaptation than those lighted with visible energy—which is almost certain to raise the general illumination level in an area.

Phosphorescent materials. Phosphorescent materials, activated by ultraviolet energy, daylight, or light from electric lamps, have been shown to have usable brightnesses of afterglow for periods of from 6 to 9 hours. Some of these have a measurable (not useful) brightness for as long as 24 hours after the source has been removed. These long-duration phosphors represent considerable progress over the materials available before World War II. Phosphorescent materials, generally combinations of calcium and strontium sulphides, now can be incorporated into adhesive tapes (plastic over-coatings), paints, and certain molded plastics. Because of the tendency of many plastics either to transmit moisture—which decomposes the sulphide—or to react directly with the phosphor, care must be exercised in the choice of a plastic to carry the phosphorescent powders. Both vinyl and polystyrene plastics have been found well suited to this application.

Phosphorescent materials are suitable only for applications where exposure to light prior to use is possible. While some can be used in spots where a visible brightness is necessary for from 6 to 9 hours, only a few of the many phosphorescent compounds have this degree of persistence. Those manufactured from zinc sulphide have high initial brightness after the light source has been removed, but their useful brightness period does not extend beyond 20 or 30 minutes. Before refinements in the processing of calcium and strontium phosphors were made in 1944, the useful brightness of these types did not extend beyond from 2 to 3 hours after activation. However, now that long-persistence phosphors are available, phosphorescent materials are, in many applications, suitable for night-long use.

Brightness reduction (decay) rates are hastened by high temperatures. At very low temperatures (60 degrees Kelvin) luminescence may be completely arrested.

Radium-Luminous materials. Phosphorescent or fluorescent salts may be activated by the bombardment of alpha rays from radium. These radium-luminous materials have been used for many years on watch and clock dials, and on the faces of other instruments that must be read in the

dark. They are the only type of commercially available luminous materials that maintain self-luminosity over long periods of time. The power source (radium) has a half-life period of approximately 1,700 years and can be considered a continuous source of energy. However, in addition to emitting alpha rays which cause the luminosity of the material, radium also emits gamma rays detrimental to the glowing salt. It is the rate of salt decomposition under the bombardment of the gamma rays that determines the useful life of a radium-luminous material. A good-quality material will be useful for over 6 months and will maintain a relatively constant brightness during this period. The actual life of a radium-luminous paint is controlled to a great extent by its initial brightness, which is varied by changing the concentration of radioactive material in the mixture. Increased brightness means increased radioactive content, increased gamma ray emission, and more rapid decomposition of the glowing salt.

Because of the expense of the radium used to activate this material (it is mixed in in the form of a salt of radium) radium-luminous paint seldom is used in large quantities or to cover large areas.

MISCELLANEOUS APPLICATIONS OF ULTRAVIOLET ENERGY

The ultraviolet energy emitted by a tungsten-filament lamp (color temperature: 3,000 degrees Kelvin) is equal to only about 1 per cent of the energy in the visible spectrum. Therefore, it is not of practical consequence. Fluorescent lamps also emit some ultraviolet, in particular the 0.3652-micron band of the mercury discharge. This radiant energy likewise is only a small fraction of the light energy emitted. Generally, illumination sources are not considered useful producers of ultraviolet radiation. Such ultraviolet as they do emit normally is composed of longer wavelengths, near the visible spectrum.

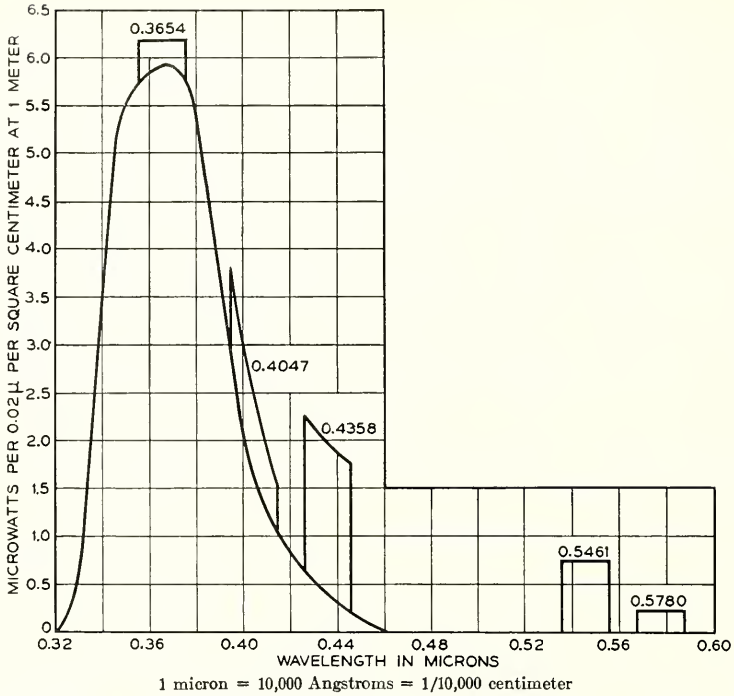
Sources of Ultraviolet Energy

Mercury arcs enclosed within ultraviolet transmitting glass or fused quartz emit ultraviolet energy in addition to light. The ultraviolet component of the energy emitted by a high-pressure quartz mercury arc may equal or be nearly twice as large as that of the visible component, depending upon lamp design.

Low-pressure quartz mercury lamps produce about 85 per cent of their total (light and ultraviolet energy) output in the ultraviolet spectrum. Over 90 per cent of their ultraviolet energy output is emitted in one band at 0.2537 micron. When an ultraviolet transmitting glass such as Vycor is substituted for fused quartz, the ultraviolet output is reduced by about 20 per cent.

Most ultraviolet sources require special circuits and external ballast for operation. A few have their ballast built into the bulb, either in the form of an incandescent filament or a low-temperature resistor, and may be attached to and operated from a standard electrical outlet.

A fluorescent type lamp with an ultraviolet emitting phosphor is available also. (See Tables 16-2 and 16-3 and Figs. 16-6 and 16-7.)



1 micron = 10,000 Angstroms = 1/10,000 centimeter

FIG. 16-6. Spectral distribution of radiant power density produced at point on plane parallel to the axis of 15-watt, 360 BL fluorescent lamp.

Table 16-2. Characteristics of Typical High-Pressure, Mercury-vapor Sources of Ultraviolet Energy

Designation	PHOTOCHEMICAL ULTRAVIOLET OUTPUT						ERYTHEMAL ULTRAVIOLET OUTPUT			
	A-H4	B-H4	C-H4 spot, E-H4 flood	A-H5	D-H1	A-H6	S-4	RS-4	RS	S-1
Rated power input (watts)	100	100	100	250	400	1000	100	100	275	400
Rated life (hours)	1000	1000	1000	1000	1000	75	*	*	*	400
Maximum over-all length (inches)	5.625	5.5	5.437	8	11	3.25	5.25	6.75	7	6.44
Useful arc length (inches)	1	1	1	1.625	2.375	1	1	1	1	
Maximum diameter (inches)	1.25	2	4.75	1.75		0.25	2.63	5	5	2.75
Base	Admed screw	Admed screw	Admed skirted screw	Mogul screw	Mogul screw	$\frac{3}{16}$″ sleeve	Admed screw	Admed screw	Med screw	Mogul screw
Transformer secondary voltage (no load)	245	245	245	250		1200	245	245	†	33
Potential drop between arc electrodes operating at rated output (volts)	130	130	130	135	135	840	130	130	†	14
Arc current (amperes) rated output operation	0.9	0.9	0.9	2.1	3.2	1.4	0.9	0.9	†	30

* Approximately 700 applications in ordinary home use, or 1,000 hours at 5 hours per start.
† This lamp has a tungsten-filament resistance and a thermal switch enlosed in its reflector-type outer envelope. It is operated without external ballast on 110, to 125-volt, 50- to 60-cycle alternating current only.

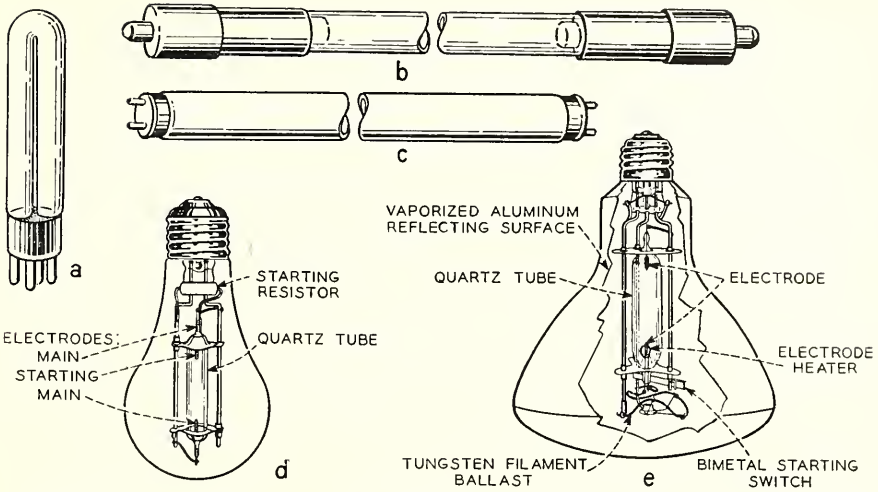


FIG. 16-7. Typical sources of ultraviolet energy: *a*. 4-watt bactericidal; *b*. 16 A22 bactericidal; *c*. 15-watt 360 BL fluorescent; *d*. S4 Sunlamp; *e*. RS sunlamp.

Eye Protection

Eye protection is essential for all who are exposed to the direct or reflected radiation from lamps emitting ultraviolet especially shortwave U.V. Ordinary window or plate glass or goggles that exclude radiations of wavelength shorter than 0.3400 micron usually are sufficient protection. However, if the radiation is intense, or is to be stared at for some time, Noviweld* glass goggles should be used. Failure to protect the eyes can result in painful inflammation of the conjunctiva, cornea, and iris; photophobia; blepharospasm; and ciliary neuralgia. Many of the unpleasant effects are temporary, but frequent repetition may result in permanent injury to the eyes.

Erythemal and Biological Ultraviolet

Generators of ultraviolet energy used as sunlamps are designed to have erythemal effectiveness resembling the peak output of direct sunlight in the region of 0.29 to 0.3 micron.

Production of vitamin D. Ultraviolet energy of 0.2970-micron wavelength has the greatest erythemal effectiveness. Energy in the 0.2537-micron wavelength appears to be between 50 and 80 per cent as effective, watt for watt. However, since the absorptance by the human skin of various wavelengths is not uniform, low-pressure, mercury-vapor-discharge sources (bactericidal lamps) and high-pressure, mercury-vapor-discharge sources (therapeutic lamps) are, for vitamin D production, about equally efficient, watt for watt.

Lamps designed to produce erythema also increase the lime, phosphorus, and carbohydrate metabolism and develop antirachitic vitamins (especially D), since the absorption of ergosterol in the human skin is maximum in the region between 0.25 and 0.3 micron.

* Trade name.

Table 16-3. Characteristics of Typical Low-Pressure, Mercury-Vapor Sources of Ultraviolet Energy[1]

DESIGNATION	NEAR ULTRAVIOLET OUTPUT					BACTERICIDAL ULTRAVIOLET OUTPUT														
	PREHEAT STARTING									COLD STARTING										
	360 BL—Fluorescent					G4T4*§ WL-4‡	G8-T5*†§ WL-8‡	G15T8*§ WL-15‡	G30T8*§ WL-30‡	WL-793‡	WL-794‡ G4-S11§	2851Q†	WL-782-10‡	WL-782-20‡	2852Q†	WL-782-30‡	ST34A18† ST34B18 ST34J18	ST16A22†	ST30A32†	ST96S36†
Rated power input (watts)	4	6	15	30	40	4	8	15	30	4	4	8	11	13	14	16	18	22	32	36
Rated life (hours)		750	1,250	1,250	1,250	2,500[2] 4,000[3]	2,500[2] 4,000[3]	2,500 4,000[3]	2,500[2] 4,000[3]	4,000	2,500	7,500	8,000	8,000	7,500	8,000	10,000	10,000	10,000	7,500
0.2537-micron ultraviolet power output after 100-hr operation (watts)[4]						0.69	1.5	2.9	7.2		0.06	1.8			3.3		4.5	2.8	6.2	8.0
0.2537-micron ultraviolet power density at point 1 meter from arc axis after 100-hr operation (microwatts/sq cm)						8.1	17	32	80	3	2.5	17	17	26	36	40	50	30	68	88
Maximum over-all length (inches)		9	18	36	48	5.75	12.125	18	36	8.25	2.3	16.125	14.75	24.75	29.375	34.75	34.5	16.125	30.125	Spiral 12 in. diam
Useful arc length (inches)			14	32		6	8.5	14	32	3	0.375	12	10	20	24	30	30	11	25	96
Maximum diameter (inches)	1.5	0.625	1	1	1.5	0.5[5]	0.625	1	1	0.875	1.375	0.520	0.625	0.625	0.520	0.625	0.620	0.6875	0.6875	0.620
Outside wall temperature at center in still air (80 F)						100	150	120	130			120			120		120	115	115	120
Base	Bay-onet	Min bipin	Med bipin	Med bipin	Med bipin	Radio 4 cont.	Min bipin	Med bipin	Med bipin	Int. screw	Int. screw	19951†	Single pin	Single pin	19951†	Single pin	19951†	Single pin	Single pin	7379†
Transformer secondary voltage (no load)	24-28 DC	115	115	210	210	115	115	115	215	230	22	2,000	950	950	3,000	950	2,000	600	600	3,000
Potential drop between arc electrodes (volts) rated output operation		48	55	100	106	55	58	55	100	100	10	300	235	325	450	410	375	200	300	8,000
Arc current (amperes)		0.145	0.31	0.35	0.42	0.093	0.16 0.175	0.30	0.34	0.040	0.35	0.030	0.045	0.045	0.030	0.045	0.045	0.120	0.120	0.045

[1] Data for lamps listed by more than one manufacturer represent an industry average which may be slightly different from the specific data on each manufacturer's product.
[2] At 3 hours per start.
[3] Continuous operation.
[4] Initial output may be 25 per cent higher.
[5] Bent tube construction makes lamp 1¼ inches wide.

* General Electric Company designation.
† Hanovia Chemical & Manufacturing Company designation.
‡ Westinghouse Electric Corporation designation.
§ Sylvania Electric Products, Incorporated, designation.

Tan, differing from erythema but likely to follow it, may result from somewhat longer wavelengths. When incident radiation exceeds wavelengths of 0.39 micron up to approximately 1.4 microns, the result is a skin reddening and a dilation of the capillaries.

Tables 16-4 and 16-5 record the reflectance and transmittance of the human skin for different wavelengths. Table 16-6 indicates a secondary peak of erythemal effectiveness at wave lengths in the neighborhood of 0.24 micron. This ultraviolet wavelength is not found in natural daylight or in the output of commercial sunlamps.

Table 16-4. Reflectance at Various Wavelengths of Average Untanned Human Skin (Caucasian)[5,11]

WAVELENGTH (micron)	REFLECTANCE (per cent)	WAVELENGTH (micron)	REFLECTANCE (per cent)
0.24	3	0.40	28
.26	4	.45	35
.28	4	.50	42
.30	5	.55	48
.32	11	.60	54
.34	16	.65	65
.36	21	.70	68

Table 16-5. Transmittance at Various Wavelengths of Different Thicknesses of Human Skin[12]

WAVELENGTH (micron)	TRANSMITTANCE (per cent)		
	0.1 mm	0.5 mm	1.0 mm
0.2537	0.00	0.00	0.00
.2894	0.01	--	—
.2967	2	—	—
.3024	8	—	—
.3132	30	0.3	0.008
.3342	42	1.3	0.02
.3663	49	3	0.08
.4050	55	5	0.3
.4359	59	7	0.5

Table 16-6. Relative Erythemal Effectiveness of Ultraviolet Energy for Average Untanned Human Skin[5,11]

WAVELENGTH (micron)	ERYTHEMAL EFFECTIVENESS (per cent)	WAVELENGTH (micron)	ERYTHEMAL EFFECTIVENESS (per cent)
0.2399	95	0.2804	6
.2482	90	.2894	25
.2537	80	.2925	70
.2576	70	.2967	100
.2654	30	.3024	50
.2675	20	.3132	2
.2700	15	.3342	0.4
.2760	5	.3663	0.12

Sunlamps. Among the most common sources of erythemal ultraviolet energy are carbon-arc and mercury-vapor-discharge lamps.

For very low ultraviolet outputs some corex-glass-bulb tungsten-filament lamps (CX type) operated at high temperature and reduced life are used. Certain fluorescent-lamp phosphors emit considerable long-wave ultraviolet energy.

Sunlamps of the type accepted by the American Medical Association are rated at 100 watts in the arc. The small quartz envelope is enclosed in an outer bulb that prevents emission of any energy of a wavelength less than 0.28 micron. The emitted ultraviolet energy of a wavelength longer than 0.28 micron is similar in nature to that from a therapeutic mercury arc, but under comparable conditions is less intense. The U.V. energy emitted is more dense than that of average daylight.

Ultraviolet Irradiation of Poultry[13]

Very little ultraviolet energy is absorbed by the feathers of poultry. To be useful it must fall on the legs, feet, comb, eyes, bill, etc., of the fowl, that is, on the bare skin. Since it is not practical for the farmer to hold the legs of each individual bird close to a sunlamp (in which case a few minutes exposure per day would suffice), he has to depend on every bird in a flock (100 to 150) getting sufficient exposure while milling around under a sunlamp 3 feet above them. To assure adequate summation of random ultraviolet reception as the birds move about, lamps should be burned from 1 to 2 hours per day. It is immaterial what time of day they are used. It is good practice to suspend the lamp over a mash hopper or water trough and burn it during feeding times to ensure the maximum number of birds getting under it. The lamp may be used in a single long exposure, or two or three shorter ones. The effect is cumulative. The best method of use depends upon individual management. Usually longer lamp life is obtained with the least number of starts.

At a height of 3 feet, the effective ultraviolet radiation from a poultry-type sunlamp covers a circular area approximately 10 feet in diameter. To utilize this to maximum advantage, as many mash hoppers and water troughs as consistent with need and convenient servicing should be located within the 10-foot area.

Where chicks are kept in battery brooders or laying hens are kept in individual pens, the problem of irradiation is somewhat complicated. If there are two rows of batteries about the best that can be done is to suspend an S-4 type lamp or its equivalent, without reflector, between the rows and halfway from the floor to the top of the batteries.

Where a single tier of batteries is used, the S-4 type with reflector, the RS-4 type, or an equivalent combination may be used in a horizontal position opposite the center of the battery and at such a distance as to confine most of the light to the battery.

From a compilation of test data and reports published by various universities and experimental stations, it is found that the use of sunlamps may be expected to do the following things:

1. Increase egg production.
2. Increase the vitamin D content of the eggs.
3. Increase the hatchability of the eggs.
4. Decrease the shell breakage attributable to thin shells.
5. Eliminate loss caused by rickets.
6. Increase the chick growth rate.
7. Produce larger and stronger pullets.

The Ohio Agricultural Experiment Station at Wooster has conducted several experiments comparing the results of sunlamp irradiation and cod-liver-oil feeding of poultry. The average results of one such test are shown in Table 16-7.

Table 16-7. Comparison between Average Results Achieved Through Cod-Liver-Oil Feeding and Sunlamp Irradiation of Poultry

	COD LIVER OIL	S-4 SUN LAMP
Average per cent hatchability, White Leghorn eggs	85.3	89.9
Average per cent hatchability, Rhode Island Red eggs	73.0	78.2
Average growth of pullets, White Leghorns		
weight—18 weeks	2.38 lb	2.46 lb
mortality—18 weeks	13	8
Average growth of pullets, Rhode Island Reds		
weight—16 weeks	2.95 lb	3.11 lb
mortality—16 weeks	14	6
Average egg production, White Leghorns		
production (per cent)	44.1	52
mortality	24	30
Average egg production, Rhode Island Reds		
production (per cent)	42.6	47.3
mortality	45.6	44.7

Photochemical Lamps and Their Uses

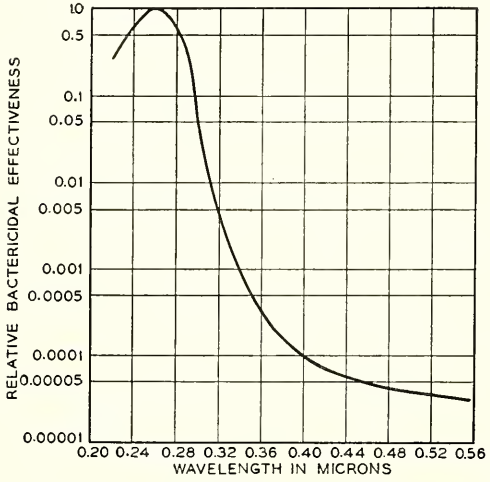
Many radiant energy applications in the photochemical field require radiators of near-visible ultraviolet energy. The uses include such diverse operations as production of uranium, of "smoke gases" for military concealment, of synthetic rubbers and some plastic preparations, and processes in photography, blueprinting, and photolithography (see Section 14). Photochemical applications merge with laundry bleaching, the treatment of wood-pulp and textile fibers, and the fixation of hydrocarbons.

In addition to an output in the near-visible ultraviolet spectral region, photochemical lamps often are required to emit light and infrared energy also. The near-ultraviolet wavelengths between 0.3 and 0.4 micron are useful in chlorination. Hydrogenation utilizes shorter wave lengths and oxygenation still shorter wave lengths than for chlorination.

In addition to control effected by the bulb transmittance, the spectral character of the emission is largely governed by the vapor pressure. Increasing vapor pressure broadens the spectral lines and causes a shift of energy output toward the longer wavelengths.

Bactericidal Ultraviolet

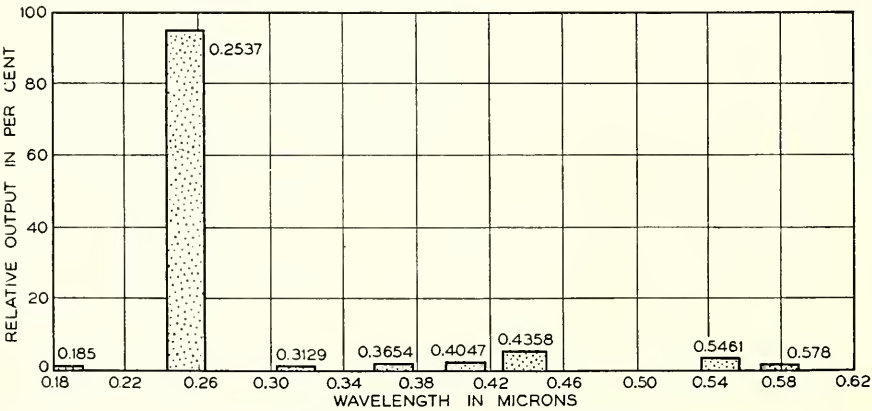
In contrast to the erythemal and tanning effectiveness the peak of abiotic or bactericidal effectiveness in controlling the growth of microorganisms or fungi spore occurs at about 0.25 micron as shown in Fig. 16-8. Because of absorption in the ozone layer of the upper atmosphere, practically none of this short-wave ultraviolet radiation reaches the earth's surface in natural daylight. Very little of it escapes from common illuminants, since it is not generated by commercial incandescent solids, and is absorbed by ordinary glass.



1 micron = 10,000 Angstroms = 1/10,000 centimeter

FIG 16-8. Relative bactericidal effectiveness of various wavelengths of radiant energy.[5]

The most practical method of generating bactericidal radiation is by the passage of an electric discharge through low (order of 0.001 atmosphere) pressure mercury vapor, usually in long tubular bulbs. Characteristics of bactericidal ultraviolet sources are shown in Table 16-1. Their output is measured (by the National Bureau of Standards) in microwatts (0.2537 micron mercury line) per square centimeter at a distance of 1 meter. From their relative spectral distribution, given in Fig. 16-9, it will be noted that approximately 95 per cent of the energy radiated is in the



1 micron = 10,000 Angstroms = 1/10,000 centimeter

FIG. 16-9. Relative spectral distribution of energy emitted by bactericidal lamps.

0.2537-micron band, coinciding with greatest lethal effectiveness. Radiations of shorter wave length are more effective in the production of ozone.

Two general classes of bactericidal lamps are available, the first generating considerable ozone, the other class producing no ozone. Ozone is a deodorant and an inhibitor of microorganism (mold) growth. However, even in safely small concentrations it may be disturbing to some individuals.

Exposure time and applications. The microorganism killing power of 0.2537 micron radiant energy is a function of the time-power density product. (See Fig. 16-10.)

General applications include preservation of meats and stored foods, reduction of germ count in air and liquids, sterilization of food and meat containers, reduction of mold growth on bread and similar foods, sterilization of medical supplies, wrappers, etc., irradiation of flat silver and dishes and of retail merchandise, and reduction of undesirable odors. (See Fig. 16-11.)

Air sterilization. In the type of installations generally made for the reduction in air ducts (recirculating systems) of air-borne pathogenic germs causing nasopharyngeal infections, the radiant energy density level choice is based upon space requirements and rate or volume of air flow and may be made high without adversely affecting the room occupants. In the irradiation of room spaces occupied by humans the energy density should be much lower. Energy should be uniformly distributed to reach as much of the upper air as practical but primarily to ensure against any undesirable effects upon the skin or the eyes of room occupants from direct or reflected ultraviolet radiation. (See Fig. 16-12.)

Upper-air disinfection with bactericidal ultraviolet energy from wall-mounted fixtures is practically limited to that part of the ultraviolet output of the fixture lying between the horizontal plane of the bactericidal lamp and a plane 45 degrees upward from it. The effectiveness of the ultraviolet in this region in turn depends on the room size and the ceiling height, the latter being the more important factor. Since bactericidal reflectors and fixtures vary greatly in the direction and the amount of their ultraviolet output, actual installations should be made only on the basis of the characteristics of the fixtures chosen. Assuming a 100 second exposure, a very general guide is: to maintain a relatively perfect disinfection in the upper air of a room there should be an average power density throughout the space of at least 50 microwatts per square centimeter.* Fixtures should be provided to secure this density. For safety where there is personnel exposure for more than 8 hours per day under ceilings of 10 feet or less height, the power density must be decreased inversely in proportion to the exposure per day with a resulting decrease in the degree of air disinfection.

* *Acceptance of Ultraviolet Lamps for Disinfecting Purposes*, Council on Physical Medicine, American Medical Association.

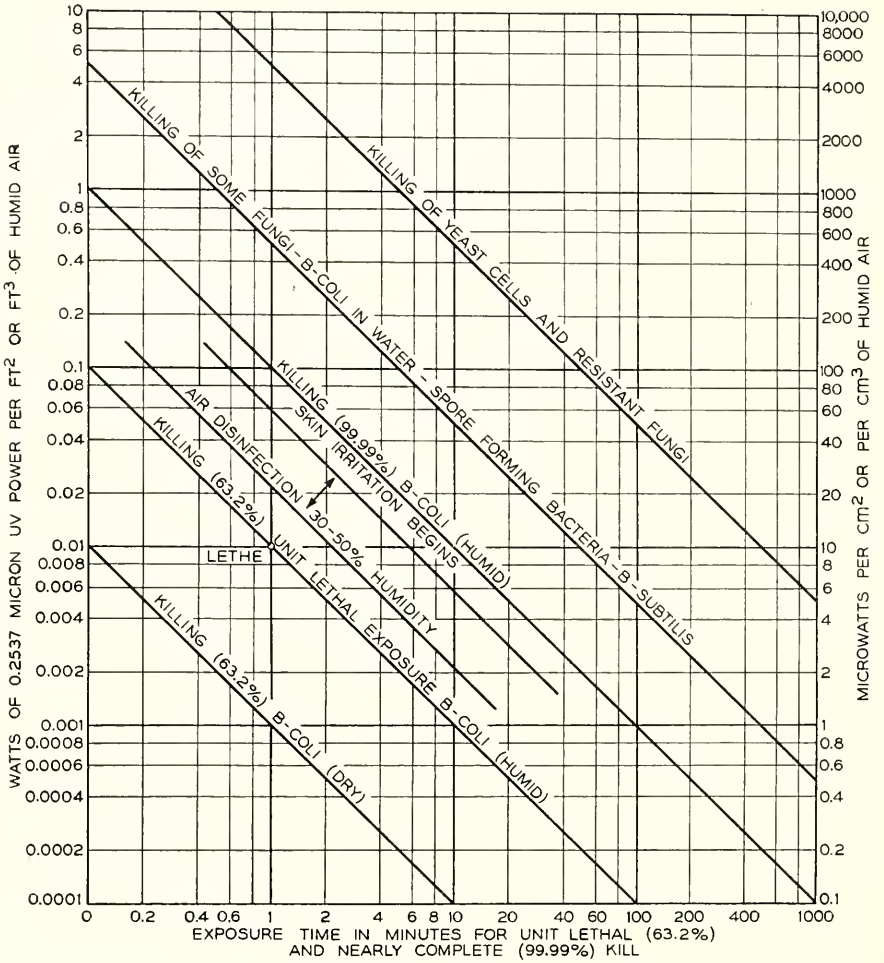


FIG. 16-10. Bactericidal exposure chart showing exposure time–power density product levels required under different humidity conditions to kill various air-borne microorganisms.[14]

It appears that when bactericidal lamps are used in a space, the volume of *make-up* air in a recirculating system can be reduced to about one-tenth that required for the same space without radiation.

The design of luminaires and the choice of interior paints are matters of critical importance when applying short-wave ultraviolet radiators. As in the case of reflectors for sources of erythemal ultraviolet, aluminum is the best practical reflecting surface. As will be noted from Fig. 16-13, white plaster is somewhat less efficient. Most oil or oxide paints reflect a negligible amount of 0.2537-micron wavelength energy and therefore can be used on walls or ceilings to reduce reflections when it is desired to restrict U.V. energy to the upper air. (See Table 16-1.)

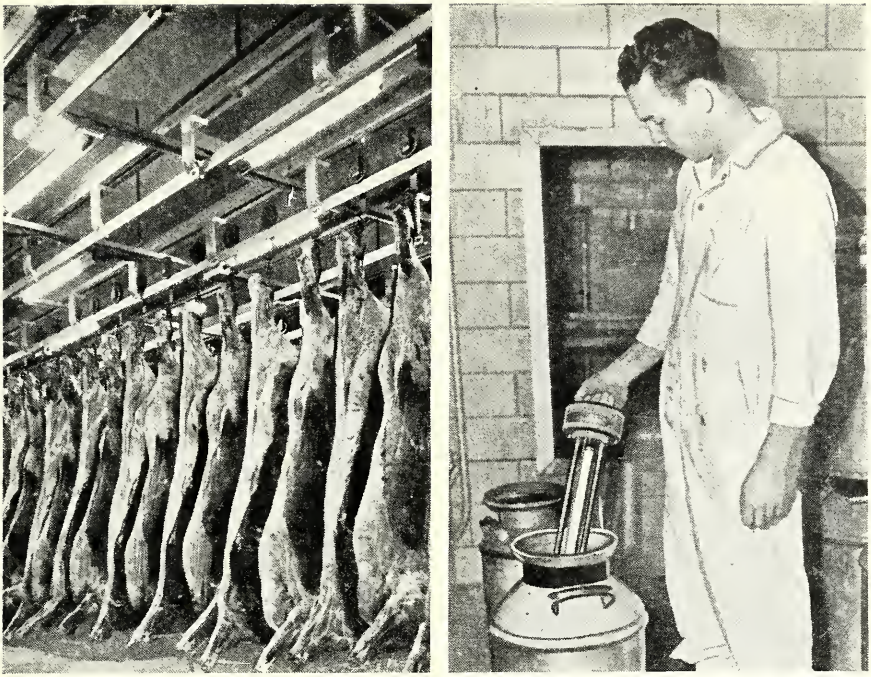


FIG. 16-11. Bactericidal ultraviolet-energy sources are used to reduce growth of mold on meat in storage and sterilize milk cans.

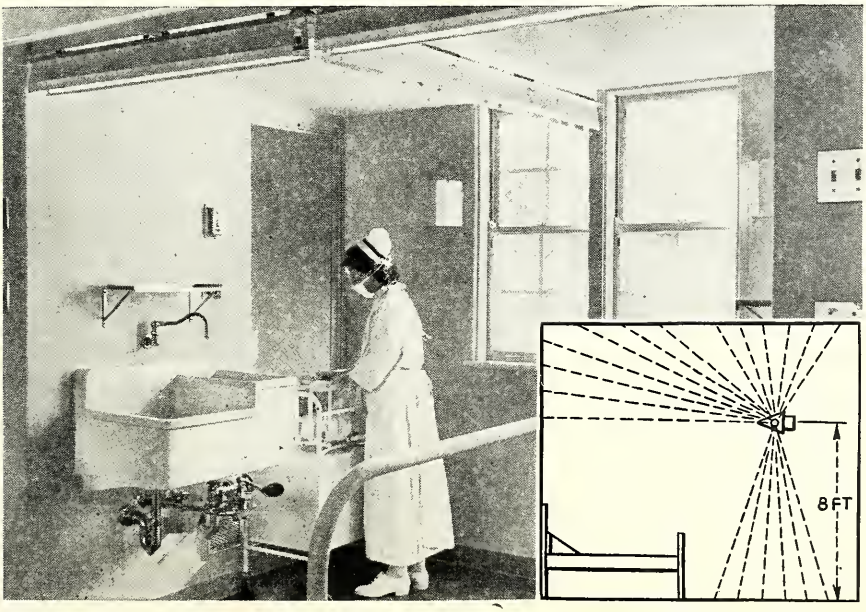
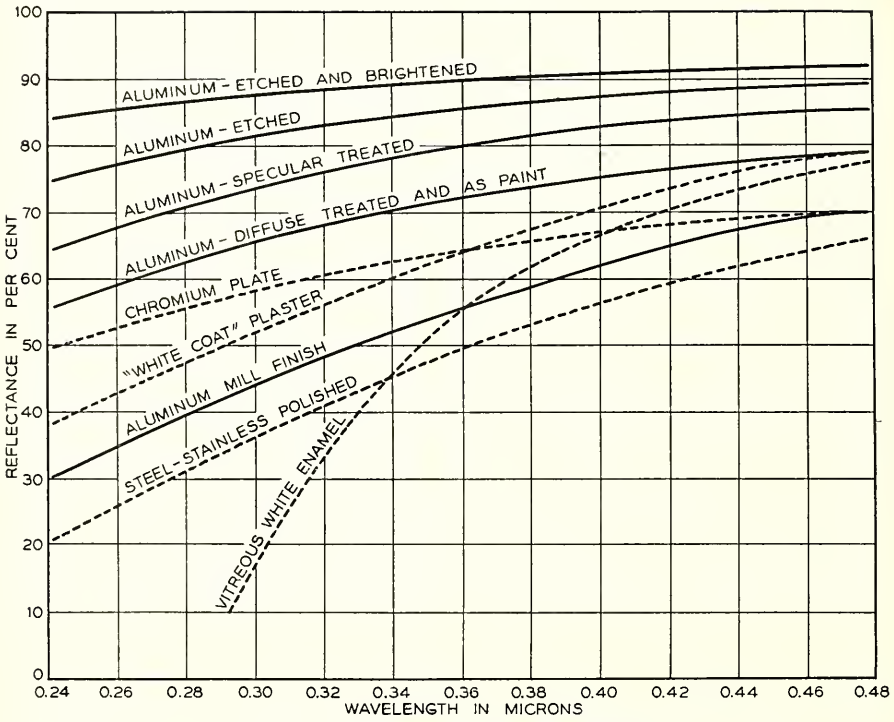


FIG. 16-12. Bactericidal ultraviolet-energy sources installed in rooms are used to disinfect the upper air and, in some cases, to provide a barrier to minimize the spread of microorganisms from one area to another.



1 micron = 10,000 Angstroms = 1/10,000 centimeter

FIG. 16-13. Spectral reflectance characteristics of various materials in the blue, violet, and ultraviolet spectral regions.[15]

Liquid sterilization. Because of high absorption in cloudy liquids, grease, and turbid water, liquid-borne bacteria are difficult to reach except at the surface or in a thin film. Penetration of clear water by 0.2537-micron energy, however, is such that approximately 50 per cent of that striking the surface will reach a depth of 3 inches.

MISCELLANEOUS APPLICATIONS OF INFRARED ENERGY

Heat may be transferred from one body to another by *conduction*, *convection*, or *radiation*, or by a combination of these processes. Examples of each are common: conduction occurs with direct contact, as when an egg is fried on a hot griddle. A household hot-air-heating plant functions by convection, an indirect-contact process depending upon the circulation of heated air or other gas. Daily and seasonal variations in the temperature of the earth's surface are the direct result of variations in the intensity of the incident radiant energy from the sun.

Transfer of some energy and therefore of heat occurs whenever radiant energy emitted by one body is absorbed by another. However, it is the electromagnetic spectrum wavelengths longer than those of visible energy

(0.76 micron) and shorter than those of radar waves that are commonly utilized for heating. Because ordinary glass and the carbon dioxide in air absorb most of the energy of wavelengths longer than 4.0 microns, only wavelengths shorter than about 4.0 microns are utilized in practice, though longer wavelengths may be emitted by infrared sources.

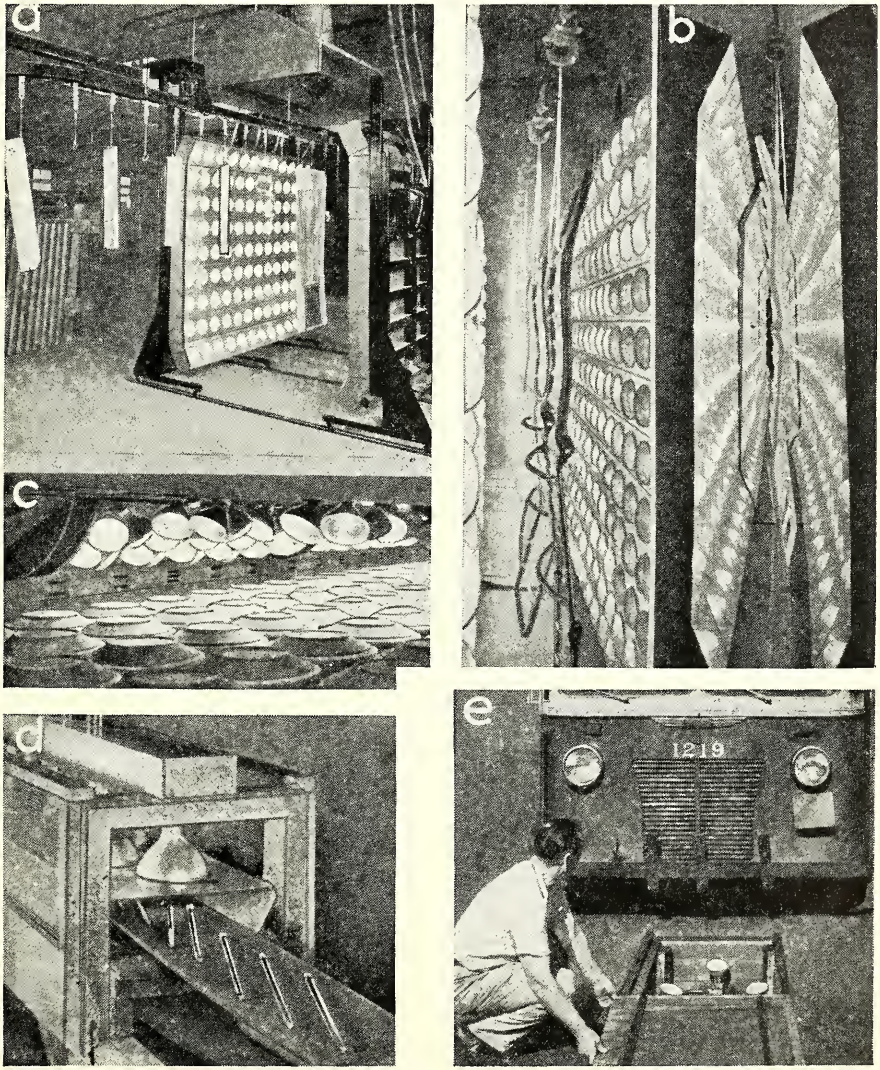


FIG. 16-14. Typical applications of infrared radiant energy: a. Baking enamel on a sheet-metal heater jacket b. Degreasing (left) and baking (right) enamel on chair frames. c. Surface drying dishware in a pottery. d. Heating plastic rods prior to a bending operation. e. Warming bus engines for winter starting.

Applications of Infrared Energy[5,18]

Infrared radiant energy is used for a variety of purposes, including (see Fig. 16-14):

Drying and baking: paints, varnishes, enamels, printer's ink, glue.

Preheating: products to speed production operations such as molding or shaping of plastics for example.

Heating: used for degreasing metals; warming wood (prior to gluing), metal parts (for shrink fit assembly).

Dehydrating: textile yarn, leather, meat, fruits, vegetables, potter's ware, sand molds.

The baking of automobile finishes was the first widely publicized commercial application of infrared radiant heating.

Industrial infrared-energy sources are employed primarily for elevating the temperature of material objects as they are exposed to the radiant energy, either in a batch or continuous conveyor-type oven. The information desired in radiant heating is contained in an expression that predicts the variation of temperature as a function of time and independent parameters such as radiant intensity and the various physical properties of the stock. The rate of temperature rise depends primarily on the difference between the energy gain of the stock by absorption of radiant energy and the loss of heat by reradiation and convection. If the temperatures of the material and its surroundings are of the same order of magnitude, loss of energy by reradiation is negligible. Most of the energy losses, then, consist of heat transferred to the surrounding atmosphere.

Factors in Baking by R diant Energy

For economical baking of industrial finishes with infrared energy the over-all absorptivity of the object should be high. Properties of both finish and undersurface determine absorptivity. Combinations consisting of transparent coatings and highly reflective materials possess low over-all absorptivities, and an attempt to employ infrared radiant heating directly to them may meet with little success. If infrared radiant energy is to be used successfully to attain high heating rates, close attention must be paid to obtaining finishes with both high absorptivities and linear absorption coefficients.

In starting a radiant-heat oven, the lamps deliver their full working intensity immediately. However, the air temperature, does not reach its equilibrium value until some time later. Therefore, in the initial period of operation both the rate of temperature rise and the maximum temperature attainable by the stock will be lower than corresponding values after the oven has operated for some time. During the preliminary period compensation may be provided as follows: the work may be run through the oven more slowly. Auxiliary heaters may be used to increase the air temperature. The energy density may be raised by using a large number of lamps.

Maximum utilization of electrical energy is obtained when the air

temperature is higher than the stock temperature. Not only higher efficiencies but also higher rates of temperature rise accompany high air temperature. As long as the air temperature exceeds the temperature attained by the stock, the absorbed radiation is completely utilized as sensible heat retained by the stock.

If infrared lamps are the only energy source, heating of the air arises from nonutilization of relatively expensive electrical energy. In combination radiant energy and convection ovens, auxiliary air heaters energized by a cheaper means such as gas or oil may be incorporated in the design. The present trend is toward well-insulated ovens.

For good results the inside surfaces of an oven tunnel should be maintained with a high infrared-reflectance material to decrease the quantity of radiation absorbed by the oven itself. The effect of using high-reflectance oven walls is to increase the radiant-energy utilization and the uniformity of irradiation.

Natural circulation of air has been used frequently for vapor removal. Though this is satisfactory in open ovens, some positive means for vapor removal must be supplied in a completely closed oven. If air stratification is undesirable, a downdraft may be used to keep the air temperature more uniform. Excessive air circulation increases the coefficient of heat transfer, and if the stock temperature is above air temperature, the over-all efficiency of the oven is decreased. The minimum circulation sufficient to remove solvent vapors and suspended solids is the most efficient if safe lamp-bulb temperatures are not exceeded.

Most of the sensible heating and the greater portion of the full temperature rise occurs during the first few minutes of exposure. During this time convectional losses of heat to the air are low or may even be negative if the air temperature is high. As more time passes, however, the additional temperature rise is relatively small, but the cumulative convectional heat losses continue to increase. The energy input increases linearly as time passes so that as the exposure time is increased, the ratio of the energy retained to the radiant energy input decreases. The use of as high energy density as permissible not only brings about rapid attainment of high temperature and high capacity for an installation, but also results in more efficient use of the available radiant energy.

Radiant-heat ovens are well adapted for multiple heat-density operation. If low initial temperature rise is desirable for producing wrinkle finishes or for driving off thinners slowly to prevent pinholing, a low-density section can be employed conveniently. This preliminary heating zone can be followed by a high-density section in which high temperatures are obtained. Other combinations of sectionalized design can be made.

Uneven heating temperatures may result if the stock has sharp changes in surface contour and varying wall thickness. Good heat conductors such as metals will tend to overcome this difficulty, especially in ovens with high air temperatures.

Today, radiant heating competes with hot-air heating. With materials for which it is applicable radiant heating has the advantage that very high

energy transfer rates are obtained which result in more compact and less costly installations. Only an actual cost analysis including a comparison of installation, maintenance, energy, and replacement costs will tell which is better for a given process. The conclusions will have regional aspects.

Many sources of infrared radiant energy are available. Open hot-wire and strip electric resistors, gas radiators, and electric-filament heat lamps are used for various types of industrial heating. Lamps have the advantage of directional energy control, oven design flexibility, high infrared output, and reduced fire hazards. Although their filaments are operated at a relatively low temperature (2,500 degrees Kelvin) as compared with standard lighting lamps, this is quite high when compared with the usual temperature of the other common types of industrial heaters.

Radiant-Heating Lamps

Radiant-heating lamps consist of gas-filled or vacuum bulbs containing either tungsten or carbon filaments designed to operate at about 2,500 and 2,200 degrees Kelvin. Although carbon-filament lamps have a higher initial efficiency, they show considerable depreciation by blackening after approximately 100 hours of operation. Tungsten-filament lamps are considered to be more economical in the long run because of their higher over-all efficiency and longer life. Some large installations of tungsten-filament lamps have been in service in excess of 10,000 hours and have required few replacements. Replacements usually are necessitated by mechanical breakage caused by handling. Lamp-filament operating life is very long.

Carbon lamps with power ratings up to 375 watts and tungsten lamps up to 1,000 watts are available. Prior to 1940 the majority of installations used 250-watt lamps. Figure 16-15 shows the radiant-energy density that may be produced by various types and arrangements of lamps.

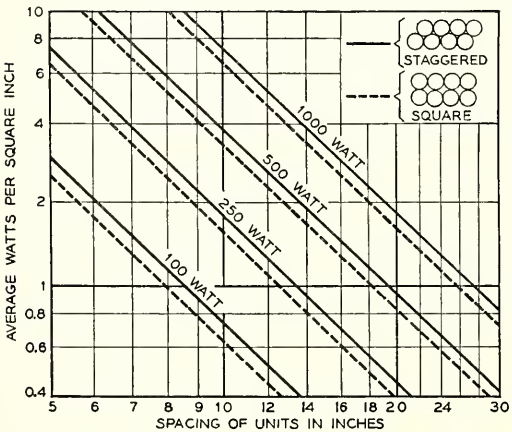
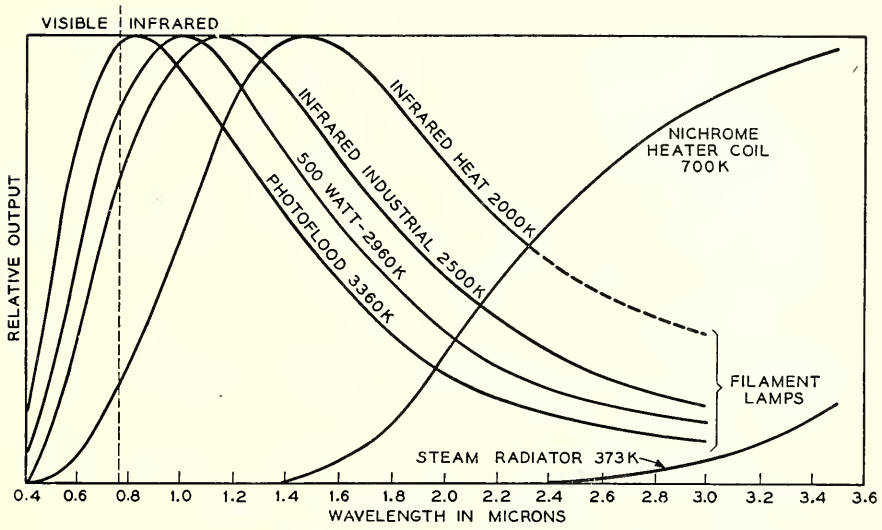


FIG. 16-15. Power density produced on plane 12 inches from lamps by different sizes and arrangements of lamps, 65 per cent efficiency assumed.[20]

Standard practice for both reflector-type and clear-bulb infrared lamps is to use mechanically attached bases rather than the cemented type, except with the higher wattage lamps, where the medium bipost base with flexible connecting leads is used. See also Fig. 16-16.

Reflecting surface. Proper application of the incandescent heating lamp requires the use of some form of reflector to direct radiant energy toward the object to be heated.



1 micron = 10,000 Angstroms = 1/10,000 centimeter

FIG. 16-16. Spectral distribution of energy from various infrared sources.

Lamps in external reflectors and with aluminum reflecting surfaces built into the bulb are employed. No auxiliary reflector is necessary with this reflector-type lamp.

With clear-bulb lamps, specular surface aluminum- and gold-plated reflectors have been employed; recent practice has been to standardize on shallow, gold-plated reflectors dimensioned for mounting on 11-inch centers.

Since uniform energy distribution is the common objective for the operating distances used in service, the beam patterns for both reflector-bulb lamps and gold reflectors are widespread rather than concentrated; beam spreads of approximately 120 degrees are used with about 60 per cent of the energy falling within the 60-degree central cone.

The average radiant energy density obtainable on a surface normal to the lamps depends upon lamp spacing, lamp wattage, and the lamp-surface distance. Though no industrial arrangement of lamps in a bank has given an *absolutely* uniform energy density over a surface normal to the lamps, at operating distances at least $1\frac{1}{2}$ times the spacing the uniformity is satisfactory for most applications.

A specification of the maximum density required without stating the minimum allowable is indefinite and can be misleading; the requirement usually is expressed in power-per-unit-area terms.

Where unusually high intensities of energy are desired over small areas, specially designed specular surface ellipsoidal reflectors can be employed to focus the emission from a clear bulb lamp on a small spot. The reflector size and surface area will depend on the amount of energy required and the size and location of the area on which it is needed. These factors also determine the wattage and filament size of the lamp required.

The deposition of paint or other air-borne solids or drippings on lamp and reflector reduces the effectiveness of the controlled radiated energy. Periodic cleaning of lamps and of transmitting and reflecting surfaces should be carried out.

Dehydration

Infrared energy is used to dry or dehydrate hides, sand molds, textiles, glue, pottery, photonegatives, paper, and a variety of meats and vegetables. The infrared dehydration rate is affected by material characteristics, thickness, and air temperature.

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APPENDIX

Table A-1. Levels of Illumination—Good Current Practice*

AREA	FOOTCANDLES MAINTAINED IN SERVICE	AREA	FOOTCANDLES MAINTAINED IN SERVICE
INTERIOR LIGHTING†			
Airplane manufacturing		**Candy making**	
Stock parts		Box department	20
Production	50	Chocolate department	
Inspection	100**	Husking, winnowing, fat extraction, crushing and refining, feeding	10
Parts manufacturing		Bean cleaning; sorting, dipping, packing, and wrapping	20
Drilling, riveting, and screw fastening	30	Milling	50
Spray booths	30	Cream making	
Sheet aluminum layout and template work; shaping and smoothing of small parts for fuselage, wing sections, cowling, etc	50	Mixing, cooking, and molding	20
Welding		Gum drops and jellied forms	20
General illumination	20	Hand decorating	50
Supplementary illumination	1,000**	Hard candy	
Sub-assembly		Mixing, cooking, and molding	20
Landing gear, fuselage, wing sections, cowling, and other large units	30	Die cutting and sorting	50
Final assembly		Kiss making and wrapping	50
Placing of motors, propellers, wing sections, and landing gear	30	**Canning and preserving**	
Inspection of assembled ship and its equipment	50	Receiving department	20
Machine tool repairs	100**	Preparation department¶	30
Armories		Container handling¶	20
Drill	10	Canning department¶	30
Exhibitions	30	Processing department	20
Art galleries		Storage and warehouse department	10
General	10	**Chemical works**	
On paintings (supplementary illumination)	50	Hand furnaces, boiling tanks, stationary driers, stationary and cavity crystallizers	5
Assembly		Mechanical furnaces, generators and stills, mechanical driers, evaporators, filtration, mechanical crystallizers, bleaching	10
Medium	20	Tanks for cooking, extractors, percolators, nitrators, electrolytic cells	20
Medium fine	50	**Churches**	
Fine	100**	Auditoriums	10
Extra fine	200**	Sunday School rooms	20
Auditoriums		Pulpit or rostrum (supplementary illumination)	20
Assembly only	10	Art glass windows	
Exhibitions	30	Light color	20
Automobile		Medium color	100**
Parking spaces	2	Dark color	200**
Showrooms (see also *Show windows*)	50	**Clay products and cements**	
Automobile manufacturing		Grinding, filter presses, kiln rooms	5
Assembly line	100**	Molding, pressing, cleaning, and trimming	20
Frame assembly	30	Color, glazing, and enameling	30
Body manufacturing		**Cleaning and pressing industry**	
Parts	30	Checking and sorting	20
Assembly	30	Dry and wet cleaning and steaming	10
Finishing and inspecting	200**	Inspection and spotting	200**
Bakeries	20	Pressing	
Banks		Machine	30
Lobby	20	Hand	50
Cages and offices	50	Receiving and shipping	10
Barber shops and beauty parlors	50	Repair and alteration	200**
Book binding		**Cloth products**	
Folding, assembling, pasting, etc	20	Cutting, inspecting, and sewing	
Cutting, Punching, and stitching	30	Light goods	30
Embossing	30	Medium-dark goods	100**
Breweries		Dark goods	200**
Brew house	5		
Boiling, keg washing, and filling	10		
Bottling	20		

* Although many of the levels shown are I.E.S.-approved (1947), the composite table still is being studied and has not been submitted for official approval.

† Also see text, Section 10.

¶ Large area, low-brightness sources of diffuse illumination are necessary where specular surfaces are in the field of view if annoying reflections are to be reduced.

** Supplementary luminaires often are used in combination with a general lighting level of not less than 20 footcandles to provide the level required on the work.

AREA	FOOTCANDLES MAINTAINED IN SERVICE
Pressing, cloth treating (oil cloth, etc.)	
Light goods	30
Medium-dark goods	50
Dark goods	100**
Coal tipples and cleaning plants	
Breaking, screening, and cleaning	10
Picking	200**
Court rooms	20
Club and lodge rooms	
Lounge and reading rooms	20
Auditoriums	10
Dairy products	20
Dance halls	5
Drafting rooms	
Prolonged close work, art drafting, and designing in detail	50
Electrical equipment manufacturing	
Impregnating	30
Insulating and coil winding	100**
Testing	50
Machining (see *Machine shops*)	
Assembling (see *Assembly*)	
Inspecting (see *Inspection*)	
Elevators, freight and passenger	10
Engraving	200**
Explosives	
Hand furnaces, boiling tanks, stationary driers, stationary and gravity crystallizers	5
Mechanical furnaces; generators and stills; mechanical driers; evaporators; filtration mechanical crystallizers	10
Tanks for cooking, extractors, percolators, nitrators	20
Farms	
Milk house	10
Fluid milk	
Boilers	10
Bottle storage	10
Bottle sorting	50
Cap washers	20
Cleaning fittings and pipes	
Cooling equipment	20
Filling and inspection	50
Gauges (on facet)	30
Laboratories	50
Loading platforms	10
Meter panels (on facet)	30
Pasteurizers	20
Receiving room	20
Scales	30
Separators	20
Storage refrigerator	10
Thermometers (on facet)	30
Vats	50
Weighing room	
Forge shops	10
Foundries	
Charging floor, tumbling, cleaning, pouring, and shaking out	10
Rough molding and core making	10
Fine molding and core making	20
Glass works	
Mix and furnace rooms, pressing and Lehr, glass-blowing machines	10
Grinding, cutting glass to size, silvering	30
Fine grinding and beveling	50
Etching, decorating, polishing, and inspecting	100**
Glove manufacturing	
Pressing, knitting, sorting	
Light goods	20
Medium-dark goods	50
Dark goods	100**
Cutting, stitching, trimming, and inspecting	
Light goods	30
Medium-dark goods	100**
Dark goods	200**
Hat manufacturing	
Dyeing, stiffening, braiding, cleaning, and Refining	
Light	20
Medium	50
Dark	100**
Forming, sizing, pouncing, flanging, finishing, and ironing	
Light	30
Medium	50
Dark	100**
Sewing	
Light	30
Medium	100**
Dark	200**
Homes	
Dining room, living room, library, sun room, entrance hall, stairways and landings, bedrooms and bathrooms	
General illumination	5
Supplementary illumination as follows:	
Reading, casual periods	20
Reading, small type, prolonged periods	40
Writing	20
Children's study tables	40
Sewing	
Average for casual periods	20
Average for prolonged periods	40
Dark goods and fine needlework	100**
Mirrors	
Dressing table, light on face	20
Bathroom, light on face	40
Game tables	
Card tables	10
Ping pong	40
Kitchen	
General illumination	10
Supplementary illumination for work counter, range, and sink	40
Laundry	
Supplementary illumination for ironer, ironing board, and tubs	40
Work bench	
Supplementary illumination	40
Hospitals	
Corridors	5
Laboratories	
General laboratory work	30
Close work	50
Lobby and reception room	20
Operating room	
General	50
Operating table	
Major operations	1,000**
Minor operations	200**
Private rooms and wards (supplementary illumination)	30
Hotels	
Lobby	20
Dining room	5
Kitchen	20
Guest rooms (supplementary illumination)	30
Corridors	10
Writing rooms (supplementary illumination)	30
Ice making—engine and compressor room	10
Inspection	
Medium	20
Medium fine	50
Fine	100**
Extra fine	200**
Jewelry and watch manufacturing	200**
Laundries	
Washing	10

AREA	FOOTCANDLES MAINTAINED IN SERVICE
Flat work ironing, weighing, listing, marking	20
Machine and press finishing, sorting	30
Fine hand ironing	50
Leather manufacturing	
Vats	5
Cleaning, tanning, and stretching	10
Cutting, fleshing, and stuffing	20
Finishing and scarfing	30
Leather working	
Pressing, winding, and glazing	
Light	30
Medium	50
Dark	100**
Grading, matching, cutting, scarfing, and sewing	
Light	30
Medium	100**
Dark	200**
Library	
Reading room	30
Stack room	10
Locker rooms	10
Machine shops	
Rough bench and machine work	20
Medium bench and machine work, ordinary automatic machines, rough grinding, medium buffing and polishing¶	30
Fine bench and machine work, fine automatic machines, medium grinding, fine buffing and polishing¶	100**
Extra-fine bench and machine work, grinding, fine work	200**
Meat packing	
Slaughtering	10
Cleaning, cutting, cooking, grinding, canning, packing	20
Milling—grain foods	
Cleaning, grinding, and rolling	10
Baking or roasting	20
Flour grading	30
Museums	
General	10
Special displays (supplementary illumination)	50
Offices	
Bookkeeping, typing, and accounting	50
Conference room	
General meetings	30
Stairways	10
Desk work	
Intermittent reading and writing	30
Prolonged close work, computing, studying, designing, reading blueprints and plans	50
Filing and index reference finding	30
Lobby	10
Mail sorting	30
Reception rooms	10
Stenographic work	
Prolonged reading of shorthand notes	50
Vault	20
Packing and boxing	10
Paint manufacturing	
General	20
Comparing mix with standard	100**
Paint shops	
Dipping, spraying, firing, rubbing, ordinary hand painting and finishing	20
Fine hand painting and finishing	50
Extra-fine hand painting and finishing (automobile bodies, piano cases, etc.)	100**
Paper-box manufacturing	
Light	20
Dark	50
Storage	5
Paper manufacturing	
Acid towers, beaters, deckers, digester house, knotters, drying cylinders, calendering, settling tank house, soda room, sulphur room, and pulp grinding	10
Bleachers, paper cutters, laybovs, trimmers, lappers, Thune press, and wood chipping	20
Hand counting, wet end of paper machine	30
Paper machine reel, paper inspection, and laboratories	50
Rewinder	100**
Storage	5
Plating	10
Power plants, engine room, boilers	
Boilers, coal and ash handling, storage battery rooms	5
Auxiliary equipment, oil switches, transformers, engines, generators, blowers, compressors	20
Control room	
Switchboards and meters	30
Post office	
Lobby	20
Sorting, mailing, etc	50
Storage	10
File room	30
Corridors and stairways	5
Printing industries	
Type foundries	
Matrix making, dressing type	100**
Font assembly—sorting	50
Hand casting	30
Machine casting	20
Photography	
Dry plate and film	2,000**
Wet plate	3,000**
Printing on metal	2,000**
Electrotyping	
Molding, routing, finishing, leveling molds	100**
Trimming	50
Blacking, tinning	30
Electroplating, washing, backing	20
Photoengraving	
Etching, staging	20
Blocking	30
Proofing	50
Tint laying, routing, finishing	100**
Printing plants	
Presses	30
Imposing stones¶	100**
Proofreading	100**
Composing	100**
Professional offices	
Waiting rooms	20
Consultation rooms	30
Examination rooms (supplementary illumination)	100**
Dental chairs (supplementary illumination)	200**
Receiving and shipping	10
Restaurants, lunch rooms, cafeterias	
Dining area	10
Food displays	50
Kitchens	20
Rubber tire and tube manufacturing	
Stock preparation	
Plasticating, milling, and Branbury	20
Calendering	30
Fabric preparation—stock cutting and bead building	30
Tube and tread tubing machines	20
Tire building	
Solid tires	20
Pneumatic tires	50
Curing department	
Tube and casing	50
Final inspection	
Tube	50

AREA	FOOTCANDLES MAINTAINED IN SERVICE
Casing	100**
Wrapping	20
Warehouse	5
Rubber goods—mechanical	
Stock preparation	
Plasticating, milling, and Branbury	20
Calendering	30
Fabric preparation—stock cutting and hose looms	30
Extruded products	30
Molded products and curing	50
Inspection	100**
Boxing	20
Warehouse	5
Sheet metal works	
Miscellaneous machines, medium bench work, punches, presses, shears, stamps, welders, spinning	30
Tin plate and similar inspection ¶	50
Schools	
Auditoriums	
Assembly only	10
Study halls	30
Class and study rooms—desk and chalkboards	30
Drawing room	50
Gymnasium	
General exercising	20
Exhibition games	30
Laboratories	
General laboratory work	30
Close work (supplementary illumination)	50
Lecture rooms	
General	30
Local illumination	50
Manual training	
General	30
Close work(supplementary illumination)	
Sewing room (supplementary illumination)	50
Sight-saving classes	50
Service space	
Stairways	10
Elevators, freight and passenger	10
Corridors	5
Storage (see *Storage and stock rooms*)	
Toilets and wash rooms	10
Shoe manufacturing—leather	
Cutting and stitching	
Cutting tables	20
Marking, buttonholing, skiving, sorting, vamping, and counting	
Light materials	20
Dark materials	100**
Stitching	
Light materials	30
Dark materials	100**
Making and finishing	
Nailers, sole layers, welt beaters and scarfers, trimmers, welters, lasters, edge setters, sluggers, randers, wheelers, treers, cleaning, spraying, buffing, polishing, embossing	
Light	20
Dark materials	100**
Storage, packing, and shipping	10
Shoe manufacturing—rubber	
Washing, coating, mill run compounding	10
Varnishing, vulcanizing, calendering, upper and sole cutting	30
Sole rolling, lining, making, and finishing processes	50
Show windows	
Isolated displays	
Dark outlying areas	
General	50
Feature displays	100**
Cities—secondary business districts	
Small towns	
General	100**
Feature displays	200**
Cities—main business areas	
General	200**
Feature displays	500**
Minimizing daylight reflections	1,000**
Soap manufacturing	
Kettle houses, cutting, soap chip and powder	10
Stamping, wrapping and packing, filling and packing soap powder	20
Stairways	10
Steel and iron manufacturing	
Billet, blooming, sheet bar, skelp, and slabbing mills	10
Boiler room, power house, foundry and furnace rooms	10
Hot sheet and hot strip mills	10
Cold strip, pipe, rail, rod, tube, universal plate, and wire drawing ¶	
Merchant and sheared plate mills ¶	
Tin plate mills	
Hot strip rolling and tinning machine dept.	10
Cold strip rolling	20
Inspection	
Black plate, bloom, and billet chipping	30
Tin plate and other bright surfaces ¶	50
Repair shops	
Rough bench and machine work	20
Medium-fine bench and machine work	30
Fine work—buffing, polishing, etc.	100**
Extra-fine work	200**
Blacksmith shop	10
Laboratories—chemical and physical	30
Carpenter and pattern shop (see *Woodworking*	
Storage	2
Stone crushing and screening	
Belt conveyor tubes, main line shafting spaces, chute rooms, inside of bins, primary breaker room, auxiliary breakers	5
Under bins	5
Screens	10
Storage battery manufacturing	
Molding of grids	20
Storage and stock rooms	
Rough bulky materials	5
Medium	10
Fine material requiring care	20
Store interiors	
Circulation areas	20
General merchandising areas	50
Show cases, wall cases, and open counter displays	100**
Feature displays	200**
Stock rooms	10
Structural steel fabrication	10
Sugar refining	
General	30
Color inspection	100**
Testing	
Rough	20
Fine	30
Extra-fine instruments, scales, etc.	100**
Textile mills	
Cotton textile mills	
Opening, mixing, picking, carding, and drawing	10
Slubbing, roving, spinning, and spooling	20
Grading	100**
Warping on comb	30
Beaming and slashing on comb	
Gray goods	20
Denims	100**
Inspection	
Gray goods (hand turning)	50
Denims (rapidly moving)	200**

AREA	FOOTCANDLES MAINTAINED IN SERVICE
Automatic tying-in, weaving	50
Drawing-in by hand	100**
Silk and rayon textile mills	
Soaking, fugitive tinting, and conditioning or setting of twist	10
Winding, twisting, rewinding and coning, quilling, slashing	30
Warping (silk or cotton system)	
On creel, on running ends, on reel, on beam, on warp at beaming	50
Drawing-in	
On heddles and reeds	10
On warp back of harness	20
On woven cloth	30
Woolen and worsted textile mills	
Carding, picking, washing, combing, twisting, dyeing	10
Drawing-in, warping	
Light goods	20
Medium-dark goods	50
Dark goods	100**
Weaving	
Light goods	20
Medium-dark goods	50
Dark goods	100**
Knitting machines	20
Theaters and motion picture houses	
Auditoriums	
During intermission	5
During picture	0.1
Foyer	10
Lobby	20
Tobacco products	
Drying, stripping, general	10
Grading and sorting	100**
Toilets and wash rooms	10
Upholstering—automobile, coach, furniture	30
Warehouse	5
Welding	
General illumination	20
Supplementary illumination	1,000**
Woodworking	
Rough sawing and bench work	20
Sizing, planing, rough sanding, medium quality machine and bench work, gluing, veneering, cooperage	30
Fine bench and machine work, fine sanding and finishing	50

EXTERIOR LIGHTING‡

Building	
General construction	10
Excavation work	2
Building exteriors and monuments	
Floodlighted	
Bright surroundings	
Light surfaces	10
Medium dark and dark surfaces	20
Dark surroundings	
Light surfaces	5
Medium dark and dark surfaces	10
Bulletin and poster boards	
Bright surroundings	
Light surfaces	50
Dark surfaces	100
Dark surroundings	
Light surfaces	20
Dark surfaces	50
Coal yards (protective)	0.2
Dredging	2
Flags, floodlighted	30
Gardens	
Statuary	1
Flower beds	0.4
Trees	0.4
Background	0.2
Industrial (protective)	0.2
Authorized entrances	2
Lumber yards	1
Prison yards	5
Quarries	5
Ship yards	
General	5
Ways and fabrication areas	10
Smoke stacks with advertising messages	20
Storage yards (outdoor)	1
Water tanks with advertising messages	20

SPORTS LIGHTING§

	INFIELD	OUTFIELD
Archery (on the target)		
Tournament		10
Recreational		5
Badminton		
Tournament		30
Club		20
Recreational		10
Baseball		
Major League	150	100
AA and AAA League	75	50
A and B League	50	30
C and D League	30	20
Semipro and Municipal League.	20	15
On seats during game		2
On seats before and after game		5
Basketball		
College and professional		50
High school		30
Recreational		10
Bathing beaches		1
Billiards (on table)		
Tournament		50
Recreational		30
General area		10
Bowling	GENERAL	ON THE PINS
Tournament	20	50
Recreational	10	30
Bowling on the green		
Tournament		10
Recreational		5
Boxing or wrestling (ring)		
Championship		500
Professional		200
Amateur		100
Seats during bout		2
Seats before and after bout		5
Clock golf		10
Croquet		
Tournament		10
Recreational		5
Curling		
Tournament		10
Recreational		5
Drill fields		5
Gymnasiums		
Exhibitions and matches		30
General exercising		20
Lockers and shower rooms		10
Handball		
Tournament		30
Club		20
Recreational		10
Football		
(Index: Distance from nearest sideline to farthest row of spectators)		
Class I Over 100 feet		100

‡ Also see text, Section 11.
§ Also see text, Section 12.

AREA	FOOTCANDLES MAINTAINED IN SERVICE
Class II 50 to 100 feet	50
Class III 30 to 50 feet	30
Class IV Under 30 feet	20
Class V No fixed seating facilities	10
Golf driving	
General on the tees	10
On vertical surface at 200 yards	3
Practice putting green	10
Horseshoes	
Tournament	10
Recreational	5
Hockey	
College or Professional	50
Amateur League	20
Recreational	10
Playgrounds	5
Polo	10
Racing	
Bicycle	20
Motor (midget auto or motorcycle)	20
Horse	20
Dog	20
Racquet	30

Rifle range	OUTDOOR	INDOOR
On target	30	50
Firing point	10	10
Range		5

AREA	FOOTCANDLES MAINTAINED IN SERVICE
Roque	
Tournament	20
Recreational	10
Shuffle board	
Tournament	10
Recreational	5
Skating	
Rink	5
Park lagoon, or pond	1
Ski slope practice	0.5
Soccer	
Professional and college	30
High school	20
Athletic field	10
Skeet shoot	
Target—vertical surface at 100 feet	30
Firing point, general	10
Squash	
Tournament	30
Club	20
Recreational	10
Swimming pools	
General	10

Soft Ball	INFIELD	OUTFIELD
Professional and championship	50	30
Semipro	30	20
Industrial League	20	10
Recreational	10	5

Tennis	LAWN	TABLE
Tournament	30	50
Club	20	30
Recreational	10	20

AREA	FOOTCANDLES MAINTAINED IN SERVICE
Toboggan slides	2
Trap shoot	
Target—vertical surface at 150 feet	30
Firing point, general	10
Volley ball	
Tournament	20
Recreational	10

TRANSPORTATION LIGHTING ‖

AREA	FOOTCANDLES MAINTAINED IN SERVICE
Depots, terminals, and stations	
Waiting room	20
Ticket offices	
General	20
Ticket rack and counters, (supplementary illumination)	50
Rest rooms and smoking room	20
Baggage checking office	20
Storage	5
Concourse	5
Platforms	5
Toilets and washrooms	10
Fire engine houses	10
Garages—automobile	
Storage	10
Repair department and washing	50
Used car lots	
Front row of cars	50
Remainder of area	10
Gasoline service stations	
Yard	10
Pump island and sales room	30
Lube room	
General	20
Work areas, lube, repair, and washing	50
Lavatories	10
Hangars—airplane	
Storage	10
Repair and maintenance	50
Highway lighting	
Highways	0.3
Intersections, circles, cloverleaves	0.4
Loading docks	5
Piers	
Freight	5
Passenger	5
Railroad yards	
Receiving	0.2
Classification	0.3
Street lighting	
Urban streets—vehicular traffic	
Light	0.8
Medium	1.0
Heavy	1.2
Vehicles	
Airplanes	30
Auto license plates	0.5
Interstate buses	30
Railroad cars	
Baggage, day coach, dining car, pullman	30
Mail bag racks and letter cases	30
Mail storage	5
Street railway, trolley bus, motor bus, and subway cars	30

‖ Also see text, Section 13.

INTERIOR WIRING

The use of electrical light sources requires that these be serviced by electrical conductor networks which for interior installations usually are described by the single word *wiring*.

Electric lighting evolved in the United States and Canada on 110-volt, secondary distribution systems. Direct-current generators were used first but a-c generators followed so quickly that only in the largest cities did direct current gain sufficient foothold between 1880 and 1900 to remain in general use today. At present most alternating current is supplied to the customer nominally at 115 to 120 volts and 60-cycle frequencies, although voltages between 110 and 130 may be found as well as frequencies of 25, 40, and 50 cycles. Except for the 25-cycle fluctuation noticeable in the output of incandescent lamps, these variations were of little concern in lighting application problems until gaseous-discharge lamps, which require auxiliary equipment, became popular.

Wiring methods and systems, except as they directly affect the choice of the lighting installation, are beyond the province of the Illuminating Engineering Society. Nevertheless, lighting and wiring are so inseparable that their interdependence must be noted. Lighting installations that otherwise might be quite satisfactory may fall short of their objective because of insufficient attention to wiring; many lighting installations which are recommended are not made because of high rewiring costs which in many cases reflect poor initial planning. Despite understandable preferences for minimum initial costs, it is necessary to evaluate the possible penalty of such minimums. Good wiring practice stresses safety, efficiency, adequacy, and convenience. Safety requirements are included in many local building codes, and are established by the National Board of Fire Underwriters, but the other requirements of good wiring are at the discretion of the designer, the customer and the industry.

Table A-2 shows the standard electrical symbols used on architectural plans.

Incandescent Lamp Characteristics Important in Wiring Design

Incandescent-lamp filaments are resistance elements. Filament lamps are available for constant-potential multiple operation with ratings from 1 or 2 to 300 volts; other filament lamps are designed for constant-current series operation. A few lamps or a large group may be operated in series on circuits of several thousand volts. The guiding factors when there is a choice available, and which have been influential in the trend toward power-supply standardization and wiring-device design, are as follows:

1. Incandescent tungsten filaments having the same power rating are of necessity longer and thinner at high voltages, and consequently are more fragile and less efficient.

2. Although tungsten filaments reach their optimum strength and efficiency between 10 and 25 volts, the resulting high current for a given wattage results in (*a*) more difficult lamp-sealing problems, especially in larger sizes, and (*b*) appreciably heavier resistance losses in the wiring system, since the latter varies as the square of the current.

3. The life-output performance of incandescent lamps is greatly affected by variations from design voltage. Therefore, a wiring system usually is designed to supply and maintain voltage conditions within 2 per cent of the rated value.

4. Series operation of incandescent lamps requires extreme uniformity of filament manufacture. Only a few different wattage ratings are available for each common circuit-current rating.

5. Incandescent lamps, except in very large sizes, have only a minor thermal lag in light output. Therefore, variations in voltage caused by the cyclic character of alternating current are sufficient to cause a noticeable pulsing or stroboscopic effect only at low frequencies (such as 25 cycles).

Note: References are listed at the end of each section.

Table A-2. Graphical Electrical Symbols for Architectural Plans*

Ceiling	Wall	
		General Outlets
○	—○	Outlet.
Ⓑ	—Ⓑ	Blanked Outlet.
Ⓓ		Drop cord.
Ⓔ	—Ⓔ	Electrical outlet; for use only when circle used alone might be confused with columns, plumbing symbols, etc.
Ⓕ	—Ⓕ	Fan outlet.
Ⓙ	—Ⓙ	Junction box.
Ⓛ	—Ⓛ	Lampholder.
$Ⓛ_{PS}$	$—Ⓛ_{PS}$	Lampholder with pull switch.
Ⓢ	—Ⓢ	Pull switch.
Ⓥ	—Ⓥ	Outlet for vapor-discharge lamp.
Ⓧ	—Ⓧ	Exit light outlet.
Ⓒ	—Ⓒ	Clock outlet. (Specify voltage.)
		Convenience Outlets
	⇒⊖	Duplex convenience outlet.
	$⇒⊖_{1,3}$	Convenience outlet other than duplex. 1=Single, 3=triplex, etc.
	$⇒⊖_{WP}$	Weatherproof convenience outlet.
	$⇒⊖_{R}$	Range outlet.
	$⇒⊖_{S}$	Switch and convenience outlet.
	⇒⊖R	Radio and convenience outlet.
	Ⓐ	Special purpose outlet. (Designate in specifications.)
	⊙	Floor outlet.
		Switch Outlets
	S	Single-pole switch.
	S_2	Double-pole switch.
	S_3	Three-way switch.
	S_4	Four-way switch.
	S_D	Automatic door switch.
	S_E	Electrolier switch.
	S_K	Key-operated switch.
	S_P	Switch and pilot lamp.
	S_{CB}	Circuit breaker.
	S_{WCB}	Weatherproof circuit breaker.
	S_{MC}	Momentary contact switch.
	S_{RC}	Remote control switch.
	S_{WP}	Weatherproof switch.
	S_F	Fused switch.
	S_{WF}	Weatherproof fused switch.
		Special Outlets
$○_{a,b,c,etc}$	$⇒⊖_{a,b,c,etc}$ $S_{a,b,c,etc}$	Any Standard Symbol as given above with the addition of a lower-case subscript letter may be used to designate some special variation of Standard Equipment of particular interest in a specific set of Architectural Plans. When used they must be listed in the Key of Symbols on each drawing and if necessary further described in the specifications.
$□_{a,b,c}$		Special auxiliary outlets. *Note:* Subscript letters refer to notes on plans or detailed description in specifications.

Panels, Circuits, and Miscellaneous

- Lighting panel board.
- Power panel board.
- Branch circuit: concealed in ceiling or wall.
- Branch circuit: concealed in floor.
- Branch circuit; exposed.
- Home run to panel board. Indicate number of circuits by number of arrows. *Note:* Any circuit without further designation indicates a two-wire circuit. For a greater number of wires indicate as follows: -/// (three wires) -//// (four wires), etc.
- Feeders. *Note:* Use heavy lines and designate by number corresponding to listing in Feeder Schedule.
- Underfloor duct and junction box. Triple system. *Note:* For double or single systems eliminate one or two lines. This symbol is equally adaptable to auxiliary system layouts.
- Ⓖ Generator.
- Ⓜ Motor.
- Ⓘ Instrument.
- Ⓣ Power transformer. (Or draw to scale.)
- Controller.
- Isolating switch.

Auxiliary Systems

- Push button.
- Buzzer.
- Bell.
- Annunciator.
- Outside telephone.
- Interconnecting telephone.
- Telephone switchboard.
- Ⓣ Bell-ringing transformer.
- D Electric door opener.
- FD Fire-alarm bell.
- F Fire-alarm station.
- City-fire-alarm station.
- FA Fire-alarm central station.
- FS Automatic-fire-alarm device.
- W Watchman's station.
- WI Watchman's central station.
- H Horn.
- N Nurse's signal plug.
- M Maid's signal plug.
- R Radio outlet.
- SC Signal central station.
- Interconnection box.
- Battery.
- Auxiliary system circuits. *Note:* Any line without further designation indicates a two-wire system. For a greater number of wires, designate with numerals in manner similar to —·—12 No. 18W 3/4 inch conduit, or designate by number corresponding to listing in schedule.

* American Standards Association Standard ASA Z32.9-1943.

6. Like other resistance elements, incandescent lamps have a unity power factor.

7. Since the resistance of cold tungsten is lower than that of hot tungsten, the initial surge of current when voltage is applied to a lamp is many times greater than the stabilized current a few seconds later; the transient current often is as much as 10 times normal current.

8. On series circuits, socket cutouts or other automatic devices may be used to short-circuit individual lamps upon burnout.

9. Stand-by battery service can be used for both a-c and d-c systems, provided a pure resistance load is supplied as in the case of incandescent lamps.

Arc- and Gaseous-Discharge Lamp Characteristics Important in Wiring Design

Electric-discharge lamps, unlike incandescent-filament lamps, are capacitance rather than resistance elements. Because they have a negative volt-ampere characteristic, a resistance or reactance "ballast" must be connected in series with them so as to maintain the circuit current at the desired value and to prevent immediate failure of the lamps.

The following factors are pertinent to wiring design for electric-discharge-lamp installations:

1. Because of the negative resistance of the typical arc, and because certain compensating features can be built into the ballasting equipment, the attainment of rated line voltage is not as essential to good lamp performance as with incandescent lamps.

2. On direct current, the line voltage must be sufficiently higher than the voltage drop of the lamp to permit arc stability.

3. Though incandescent lamps operate satisfactorily at reduced output and increased life from almost 0 to 100 per cent rated voltage, discharge lamps are more limited. Sudden voltage drops, even if not a very large percentage of rated voltage, may cause lamps to flicker or to cease operating. Similarly, low initial voltages may prevent lamps from starting.

4. Series operation of some discharge lamps is quite feasible, provided they are not of a type wherein there are appreciable characteristic differences between cold and hot operation. On high-voltage series circuits lamps can be dimmed satisfactorily to a small percentage of normal output by reducing the current in the circuit.

5. The light output of discharge lamps follows the input current very closely. Therefore, cyclic variations caused by alternating current are quite noticeable on all low frequencies. This stroboscopic effect is perceptible at 60 cycles when moving objects are illuminated. Lead-lag ballasts or operation on different phases of multiple-phase circuits minimize this characteristic.

6. Discharge lamps have less than unity power factor. The combined power factor of lamp and ballast will be less than unity also if a means for power factor correction is not provided.

7. Except for lamps with preheat cycles or lamps that change characteristics appreciably during warm-up periods because of pressure build-up, there is no basic difference between starting and operating circuit requirements.

8. Many types of discharge lamps can be used on direct current, although d-c operation is not as flexible as a-c operation.

9. Although discharge lamps operated on alternating current require ballast, the latter may be simpler and cheaper if the supplied voltage can be used directly instead of through a transformer.

10. Long, tubular, low-pressure, gaseous-discharge lamps can be operated in series and, if mounted end to end, require no secondary wiring system, because the lamps themselves act as the circuit conductors.

Electrical Distribution Systems for Building Interiors

An electrical system should take care not only of the existing known loads, but also the foreseeable future loads. The voltage drop should be a practical minimum. Last but not least, the electrical system should be installed in such a manner that safety to life, limb, and property will be assured. See Fig. A–1.

Wiring Methods

The type of wiring that may be used is regulated to some extent by codes, but in most cases the designer has a choice of several systems which must be properly evaluated from the standpoints of flexibility and of ultimate cost in operation. The various systems permitted by the National Electrical Code together with the article covering each is as follows:

Open wiring on insulators	Article 320
Concealed knob and tube	Article 324
Armored cable (BX)	Article 334
Nonmetallic sheathed cable	Article 336
Rigid metal conduit	Article 346
Electric metallic tubing	Article 348
Flexible metal conduit	Article 350
Surface metal raceway	Article 352
Underfloor raceway	Article 354

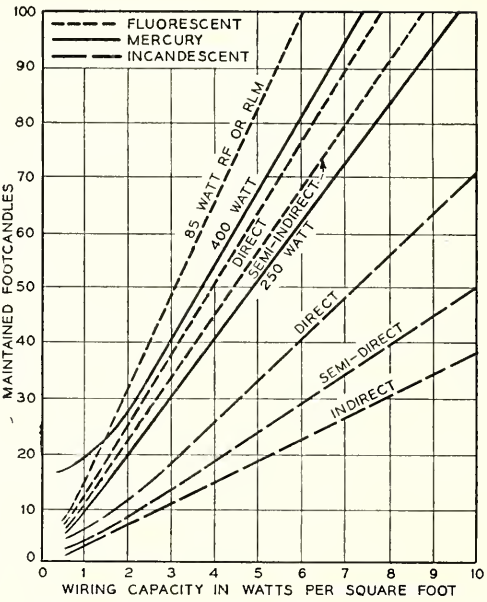


FIG. A-1. Approximate wiring capacity required to maintain a given illumination level in a room of average size by means of various types of lighting installations.

A complete study must be made of the type of building construction and the type of occupancy as well as code limitations of each system before a final choice is made.

Voltages

Interior-lighting circuits normally carry a 115- or 120-volt potential; industrial plants sometimes utilize 230-volt circuits for lighting. Constant current, or series-lighting, systems, using higher voltages such as are common for street lighting, are not used in buildings but have been used in exterior protective lighting systems.

Power circuits normally are rated 230-volt or 460-volt. Small- and medium-sized motors usually are operable on 230 and 460 volts, while motors of larger capacities may be rated at 2,300 volts or higher.

Voltage Drop

When an electric current flows through a conductor, a part of the electrical energy is dissipated as heat, and the conductor temperature is raised. The power P so dissipated as heat (measured in watts) is equal to the resistance of the conductor R (ohms) multiplied by the square of the current I (amperes) or ($P = I^2R$).

For example, the resistance of 100 feet of No. 12 wire is approximately 0.16 ohm. With a 10-ampere current flow in a No. 12 conductor, and a *total length of wire* of 100 feet, the energy lost in the form of heat will be 10 x 10 x 0.16, or 16 watts. If the current is doubled to 20 amperes, the loss in watts will be 64 or (20 x 20 x 0.16). Thus, when the curent is doubled, the energy loss and the heating effects are multiplied by 4. It is important to keep this in mind. (See Tables A-3 and A-4.)

Furthermore, voltage drop E is equal to the resistance of the conductor R (ohms) multiplied by the current I (amperes) or ($E = IR$).

In other words, voltage drop is evidence of wasted electricity. With supply voltage below the voltage rating of the device the percentage decrease in heat produced by any electrically heated device is approximately twice the percentage decrease in the voltage delivered to the device.

Table A-3. Dimensions, Weights, and Resistance of Pure Copper Wire

GAUGE NO. AWG		DIAM. (in.)	AREA CIRCULAR MILS (d^2) (1 mil = 001 in.)	WEIGHT BARE		LENGTH (feet per pound)	RESISTANCE AT 77 F		
				Lb per Mile	Lb per 1,000 Feet		Length (feet per ohm)	Ohms per 1000 ft	Ohms per pound Bare
Stranded		1.152	1,000,000	16,315	3,090	0.3235	92,592	0.0108	0.000003493
		1.031	800,000	13,042	2,470	.4024	74,074	.0135	.000005465
		.964	700,000	11,405	2,160	.4628	64,935	.0154	.000007128
		.893	600,000	9,768	1,850	.5400	55,555	.0180	.00000973
		.814	500,000	8,131	1,540	.6488	46,296	.0216	.00001402
		.728	400,000	6,547	1,240	.8060	37,037	.0270	.00002176
		.575	250,000	4,076	772	1.30	23,201	.0431	.0000558
Solid	0000	.4600	211,600	3,382	640.5	1.55	20,010	.0500	.0000780
	000	.4096	167,800	2,682	507.9	1.97	15,870	.0630	.0001241
	00	.3648	133,100	2,127	402.8	2.48	12,580	.0795	.0001973
	0	.3248	105,500	1,687	319.5	3.13	9,980	.1002	.0003137
	1	.2893	83,690	1,337	253.3	3.95	7,914	.1264	.0004988
	2	.2576	66,370	1,061	200.9	4.98	6,276	.1593	.0007931
	3	.2294	52,640	841	159.3	6.28	4,977	.2009	.001261
	4	.2043	41,740	667	126.4	7.91	3,947	.2533	.002005
	5	.1819	33,100	529	100.2	9.98	3,120	.3195	.003188
	6	.1620	26,250	420	79.46	12.58	2,482	.4028	.005069
	8	.1284	16,510	264	49.98	20.01	1,561	.6405	.01282
	10	.1018	10,380	166	31.43	31.82	981.8	1.018	.03241
	12	.0808	6,530	105	19.77	50.59	617.5	1.619	.08193
	14	.0640	4,107	66	12.43	80.44	388.3	2.575	.2071
	16	.0508	2,583	41	7.82	127.90	244.2	4.094	.5237
	18	.0403	1,644	26	4.92	203.40	153.6	6.510	1.324
	20	.0319	1,022	16	3.09	323.4	96.6	10.35	3.348
	22	.0254	642	10.3	1.95	514.2	60.75	16.46	8.464
	24	.0201	404	6.46	1.22	817.7	38.21	26.17	21.40
	26	.0159	254	4.06	.77	1,300	24.03	41.62	54.11
	28	.0126	159.8	2.55	.48	2,067	15.11	66.17	136.8
	30	.0100	100.5	1.61	.30	3,287	9.50	105.2	345.9
	32	.0080	63.2	1.01	.19	5,227	5.977	167.3	874.4
	34	.0063	39.7	.635	.12	8,310	3.759	266.0	2,211
	36	.0050	25.0	.400	.076	13,210	2.364	423.0	5,590
	38	.0040	15.7	.250	.047	21,010	1.487	672.6	14,130
	40	.0031	9.89	.158	.030	33,410	.935	1069.0	35,730
	42	.0025	6.22	.100	.019	52,800	.588	1,701	89,800
	44	.0020	3.91	.064	.012	82,500	.370	2,703	223,000
	46	.0016	2.46	.041	.008	128,800	.233	4,299	552,800
	48	.0012	1.55	.023	.004	229,600	.146	6,836	1,573,000
	50	.0010	0.97	.016	.003	330,000	.092	10,870	3,587,000

Table A-4. Circuit Length for a 2 Per Cent Voltage Drop

(Single-phase, two-wire, 115 volts, 60 cycles)

TYPE R COPPER WIRE			CIRCUIT LENGTH, ONE WAY* (feet)
SIZE		MAXIMUM CURRENT (amperes)	
14	AWG	15	29
12	AWG	20	35
10	AWG	30	37
8	AWG	40	44
6	AWG	55	51
4	AWG	70	64
2	AWG	95	75
00	AWG	145	99
0000	AWG	195	116
500,000	Cir. Mils	320	168
1,000,000	Cir. Mils	455	237
2,000,000	Cir. Mils	560	384

* For unity power factor loads.

To compensate for voltage drop, either
(1) Reduce the length of the line by relocating control centers, or
(2) Increase conductor size, or
(3) Recircuit for less wattage and current per circuit or feeder.

Power Factor

Power in a resistance circuit (no inductance or capacitance) is always equal to volts x amperes. In this type of circuit, the alternating current is in phase or in step with the voltage and the power factor is unity or 100 per cent.

Where both resistance and inductance are found in an a-c circuit, the current lags behind the voltage, causing the *apparent power* (volts x amperes) to be greater than the *true power* (volts x amperes x power factor). The ratio of true power to apparent power in an a-c circuit is expressed by the *power factor*. When the current lags it is described as a lagging power factor and, conversely, if the current leads, as in a capacitive circuit, it is described as a leading power factor.

$$\text{Power factor} = \frac{\text{True power}}{\text{Apparent power}} = \frac{\text{Watts}}{\text{Volt-amperes}}$$

$$\text{Watts} = \text{Volt-amperes} \times \text{power factor}$$

The greater the amount of inductance in a circuit, the lower the power factor. In commercial and industrical installations the power factor usually is lagging. If is remains under 85 per cent it is considered low and invariably a customer is charged more by the central station for this condition. Improvement of power factor is made to reduce useless reactive power on circuits, to improve voltage regulation, and to reduce energy and demand charges.

Systems

There are a number of systems that may be used as a means in distributing electrical energy, namely:

1. Direct current —two- or three-wire
2. Single phase (ac) —two- or three-wire
3. Two phase (ac) —three-, four-, or five-wire
4. Three phase (ac) —three- or four-wire

Direct current and single-phase alternating current. The direct current and single-phase alternating current (two- or three-wire) systems, rated 115/230 and 120/240 volts, commonly are used for lighting and miscellaneous purposes. Motor loads in excess of 5 horsepower generally are not connected to these systems. The neutral wire is grounded and should, therefore, be "solid" (not capable of being disconnected) throughout the system. Branch circuits may be two-wire, 115- or 230-volt, or three-wire, 115- or 230-volt. Feeders are chiefly three-wire, except where motor loads only (230-volt) are served, in which case two-wire feeders are used.

Two-phase alternating current. Two-phase systems may employ three, four, or five wires. The two-phase, four-wire system is essentially two single-phase, two-wire systems. The two-phase, five-wire system is essentially two single-phase, three-wire systems with a common neutral. The lighting load is connected to each phase as though it were single-phase, either two- or three-wire, care being exercised to be sure that both phases are balanced as well as possible. Motors are connected to all four phase wires.

In the case of a two-phase, three-wire system, a common wire takes the place of two of the four wires of the four-wire, two-phase system. The common wire usually is grounded solidly. The voltage between the two-phase wires is 1.41 times greater than between the common wire and one of the phase wires; in other words, if the voltage between the common wire and one of the phase wires is 120 volts, then the voltage between the two-phase wires is 170 volts. Lighting is connected between the common

and each phase wire; motors are connected to all three wires. The balancing of lighting circuit loads is important to assure equal loads on each side of the common wire.

Three-phase alternating current. The three-phase, three-wire system generally is used for power loads, the voltage being 230 or 460 volts. Two-wire, single-phase or three-wire, three-phase branch circuits may be taken from this system. Three-phase, three-wire, 115-volt systems seldom are used today.

The three-phase, four-wire system is used both for power and light, the fourth wire being a neutral. Power loads are taken from the three-phase wires, and lighting is connected between any one of the phase wires and the neutral wire. The voltage across the phase wires generally is 208 volts and between any phase wire and the neutral it is 120 volts; however, this system may be expanded readily to three-phase, four-wire, 240/415 volt grounded neutral, with the resulting economy accomplished by the use of standard transformers.

In applying any of these systems to the loads they are to serve, it is well to remember that it is not good practice to supply lamps and motors with more than fractional horsepower ratings from the same circuit. Reasons for this warning are:

1. A voltage drop is caused by the heavy starting current when motors are started. One result is dimming or flickering of the light emitted by lamps in the circuit.
2. Interruptions caused by overloads on circuits are more common in motor circuits.
3. To render satisfactory service, lamps must operate within closer voltage limits than motors, therefore lighting circuits should be designed for less voltage drop than motor circuits.
4. Motor loads will operate more economically on higher voltage than will lighting loads, and a variation of 10 per cent is permissible in motor circuits though it is not economical for normal operation. A 2 per cent drop usually is allowed in lighting circuits.

Material Standards

Specifications for construction and performance of electrical roughing-in fittings and raceways and of finishing materials are found in the Standards of the Underwriters Laboratory, Inc. (in Canada, in the specifications of the Canadian Standards Association). In the use of materials for which there are Underwriters Standards, it is important to be assured of compliance with such standards. The Underwriters Laboratory, Inc., publishes at regular intervals a *List of Inspected Electrical Materials* and all materials so listed bear evidence of Underwriters' approval. Permission to use materials not "listed" must be secured. (See Tables A-5 and A-6.)

Aluminum conductors. Insulated aluminum conductors for building wires and cables are proposed (1947) because of the acute copper shortage. The National Board of Fire Underwriters has approved the use of such insulated conductors of No. 6 gauge and larger for installation in "approved raceways or open work, in dry locations only." Connectors or lugs for such aluminum conductors shall be of the "solderless type applied by means of pressure or compression."

The foregoing restrictions surrounding the use of such conductors may be modified later with the advent of more approved type of connectors for No. 14 gauge to No. 8 gauge.

Type RV (60C) insulation is being applied at present on No. 6 and No. 12 gauge wire and Type RH (75C) insulation on No. 6 gauge and larger wire. The current-carrying capacity of aluminum conductors shall be taken as 84 per cent of allowable capacities for the same sizes of copper conductors with the same kind of insulation.

The conductivity of aluminum is 61 per cent, as compared with 97 per cent for copper. The resistance is 1.59 times that of equal cross-sectional areas of copper. This is important in application, since it increases the IR voltage drop and I^2R power loss.

The specific gravity of aluminum is approximately 31 per cent that of copper; hence the weight of insulated aluminum conductors may be only 40 per cent that of insulated copper, depending upon gauge sizes and type of insulation.

Table A-5. Classification and Uses of Various Types of Conductors*

TRADE NAME	TYPE LETTER	MAXIMUM OPERATING TEMPERATURE	SPECIAL PROVISIONS
Rubber-covered fixture wire—Solid or stranded	RF-64	60 C 140 F	Fixture wiring. Limited to 300 volts
	RF-32	60 C 140 F	Fixture wiring, and as permitted in section 3103.
Rubber-covered fixture wire—flexible stranding	FF-64	60 C 140 F	Fixture wiring. Limited to 300 volts
	FF-32	60 C 140 F	Fixture wiring.
Thermoplastic-covered fixture wire—solid or stranded	TF	60 C 140 F	Fixture wiring, and as permitted in section 3103.
Thermoplastic-covered fixture wire—flexible stranding	TFF	60 C 140 F	Fixture wiring.
Cotton-covered, heat-resistant, fixture wire	CF	90 C 194 F	Fixture wiring. Limited to 300 volts
Asbestos-covered, heat-resistant, fixture wire	AF	125 C 257 F	Fixture wiring. Limited to 300 volts
Code rubber	R	60 C 140 F	General use.
Heat-resistant rubber	RH	75 C 167 F	General use.
Moisture-resistant rubber	RW	60 C 140 F	General use and wet locations.
Latex rubber	RU	60 C 140 F	General use.
Thermoplastic	T	60 C 140 F	General use. No. 14 to 4/0 inclusive. Open work No. 14 to 2,000,000 cir. mils
Moisture-resistant thermoplastic	TW	60 C 140 F	General use and wet locations. No. 14 to 4/0 inclusive. Open work No. 14 to 2,000,000 cir. mils

* National Electrical Code. In Canada refer to Canadian Standards Association Requirements.

Note: The rubber insulations include those made from natural and synthetic rubber, neoprene, and other vulcanizable materials.

Thermoplastic insulation may stiffen at temperatures below minus 10 C (14 F) and care should be used in its installation at such temperatures.

1. *Temperature Limitations.* No conductor shall be used under such conditions that its temperature, even when carrying current, will exceed the temperature specified in the table for the type of insulation involved.

2. *Wet Locations.* Insulated conductors used underground, in concrete slabs or other masonry in direct contact with earth, in wet locations, or where condensation or accumulation of moisture within the raceway is likely to occur, shall be moisture-resistant, rubber-covered (type RW); moisture-resistant, thermoplastic-covered (type TW); lead-covered; or of a type approved for the purpose.

Such conductors are not suitable for direct burial in the earth without approved mechanical protection.

3. *Corrosive Conditions.* Conductors exposed to oils, greases, vapors, gases, fumes, liquids, or other substances having a deleterious effect upon the conductor or insulation shall be of a type approved for the purpose.

Table A-5—Continued

TRADE NAME	TYPE LETTER	MAXIMUM OPERATING TEMPERATURE	SPECIAL PROVISIONS
Thermoplastic and asbestos	TA	90 C 194 F	Switchboard wiring only
Varnished cambric	V	85 C 185 F	Dry locations only. Smaller than No. 6 by special permission
Asbestos and varnished cambric	AVA	110 C 230 F	Dry locations only
Asbestos and varnished cambric	AVL	110 C 230 F	Wet locations
Asbestos and varnished cambric	AVB	90 C 194 F	Dry locations only
Asbestos	A	200 C 392 F	Dry locations only. Not for general use. In raceways, only for leads to or within apparatus. Limited to 300 volts
Asbestos	AA	200 C 392 F	Dry locations only. Open wiring. Not for general use. In raceways, only for leads to or within apparatus. Limited to 300 volts
Asbestos	AI	125 C 257 F	Dry locations only. Not for general use. In raceways, only for leads to or within apparatus. Limited to 300 volts
Asbestos	AIA	125 C 257 F	Dry locations only. Open wiring. Not for general use. In raceways, only for leads to or within apparatus
Paper		85 C 185 F	For underground service conductors, or by special permission
Slow-burning	SB	90 C 194 F	Dry locations only. Open wiring and in raceways where temperatures will exceed those permitted for rubber-covered or varnished cambric-covered conductors
Slow-burning weatherproof	SBW	90 C 194 F	Dry locations only. Open wiring only
Weatherproof	WP	80 C 176 F	Open wiring by special permission where other insulations are not suitable for existing conditions.

Table A-6. Allowable Current-Carrying Capacities of Conductors in Amperes

(Not more than three conductors in raceway or cable. Based on room temperature of 30 C, 86 F)

SIZE AWG MCM	RUBBER TYPE R TYPE RW TYPE RU (14-6) / THERMO-PLASTIC TYPE T (14-410) TYPE TW (14-410)	RUBBER TYPE RH	PAPER / THERMO-PLASTIC ASBESTOS TYPE TA / VAR-CAM TYPE V / ASBESTOS VAR-CAM TYPE AVB	ASBESTOS VAR-CAM TYPE AVA TYPE AVL	IMPREG-NATED ASBESTOS TYPE AI (14-8) TYPE AIA	ASBESTOS TYPE A (14-8) TYPE AA
14	15	15	25	30	30	30
12	20	20	30	35	40	40
10	30	30	40	45	50	55
8	40	45	50	60	65	70
6	55	65	70	80	85	95
4	70	85	90	105	115	120
3	80	100	105	120	130	145
2	95	115	120	135	145	165
1	110	130	140	160	170	190
0	125	150	155	190	200	225
00	145	175	185	215	230	250
000	165	200	210	245	265	285
0000	195	230	235	275	310	340
250	215	255	270	315	335	—
300	240	285	300	345	380	—
350	260	310	325	390	420	—
400	280	335	360	420	450	—
500	320	380	405	470	500	—

1. *Aluminum Conductors.* For aluminum conductors, the allowable current-carrying capacities shall be taken as 84 per cent of those given in this table for the respective sizes of copper conductor with the same kind of insulation.

2. *Bare Conductors.* If bare conductors are used with insulated conductors, their allowable current-carrying capacity shall be limited to that permitted for the insulated conductor with which they are used.

3. *More Than Three Conductors in a Raceway.* Table A-6 gives the allowable current carrying capacity for not more than three conductors in a raceway or cable. If the number of conductors in a raceway or cable is from four to six, the allowable current-carrying capacity of each conductor shall be reduced to 80 per cent of the values in Table A-6. If the number of conductors in a raceway or cable is from 7 to 9, the allowable current-carrying capacity of each conductor shall be reduced to 70 per cent of the values in Table A-6.

4. *Neutral Conductor.* A neutral conductor which carries only the unbalanced current from other conductors, as in the case of normally balanced circuits of three or more conductors, shall not be counted in determining current-carrying capacities as provided for in the preceding paragraph.

In a three-wire circuit consisting of two-phase wires and the neutral of a four-wire, three-phase system, a common conductor carries approximately the same current as the other conductors and is not therefore considered as a neutral conductor.

5. *Ultimate Insulation Temperature.* In no case shall conductors be associated together in such a way with respect to the kind of circuit, the wiring method employed, or the number of conductors that the limiting temperature of the conductors will be exceeded.

6. *Use of Conductors With Higher Operating Temperatures.* If the room temperature is within 10 degrees C of the maximum allowable operating temperature of the insulation, it is desirable to use an insulation with a higher maximum allowable operating temperature, although insulation can be used in a room temperature approaching its maximum allowable operating temperature limit if the current is reduced in accordance with the table of correction factors for different room temperatures.

7. *Voltage Drop.* The allowable current-carrying capacities in Table A-6 are based on temperature alone and do not take voltage drop into consideration.

8. *Overcurrent Protection* If the standard ratings and settings of overcurrent devices do not correspond with the ratings and settings allowed for conductors, the next higher standard rating and setting may be used, but not exceeding 150 per cent of the allowable carrying capacity of the conductor.

9. *Deterioration of Insulation.* It should be noted that even the best grades of rubber insulation will deteriorate in time, so that eventually they will need to be replaced.

Table A-6—Continued

SIZE AWG MCM	RUBBER TYPE R TYPE RW TYPE RU (14-6) / THERMOPLASTIC TYPE T (14-410) TYPE TW (14-410)	RUBBER TYPE RH	PAPER / THERMOPLASTIC ASBESTOS TYPE TA / VAR-CAM TYPE V / ASBESTOS VAR-CAM TYPE AVB	ASBESTOS VAR-CAM TYPE AVA TYPE AVL	IMPREGNATED ASBESTOS TYPE AI (14-8) TYPE AIA	ASBESTOS TYPE A (14-8) TYPE AA
600	355	420	455	525	545	—
700	385	460	490	560	600	—
750	400	475	500	580	620	—
800	410	490	515	600	640	—
900	435	520	555	—	—	—
1,000	455	545	585	680	730	—
1,250	495	590	645	—	—	—
1,500	520	625	700	785	—	—
1,750	545	650	735	—	—	—
2,000	560	665	775	840	—	—
CORRECTION FACTOR FOR ROOM TEMPERATURES OVER 30 C (86 F)						
C F						
40 104	.82	.88	.90	.94	.95	—
45 113	.71	.82	.85	.90	.92	—
50 122	.58	.75	.80	.87	.89	—
55 131	.41	.67	.74	.83	.86	—
60 140	—	.58	.67	.79	.83	.91
70 158	—	.35	.52	.71	.76	.87
75 167	—	—	.43	.66	.72	.86
80 176	—	—	.30	.61	.69	.84
90 194	—	—	—	.50	.61	.80
100 212	—	—	—	—	.51	.77
120 248	—	—	—	—	—	.69
140 284	—	—	—	—	—	.59

Table A-7. Minimum Service Entrance Conductor Capacity and Service Equipment Ratings

FLOOR AREA (square feet)	INDIVIDUAL EQUIPMENT CIRCUIT LOADS (total watts)*	CAPACITY SERVICE CONDUCTOR (amperes)	RATING OF SERVICE EQUIPMENT		
			Circuit Breakers	Switch	Fuse
Up to 1,000	3,500	60	70	60	60
To 1,500	4,200	65	70	100	70
To 3,000	8,800	85	90	100	90
To 4,000	9,500	100	100	100	100

* This table provides service sizes adequate for normal lighting and portable appliance loads and for a range and a water heater in addition to the individual equipment load shown. If these wattages are to be exceeded, service size should be increased accordingly. If, however, the initial wattages are less than those shown, the service sizes should be at least those given here so that future growth in load may be accommodated.

Residential Wiring

In the laying out of an electrical system for a residence, Table A-9 prepared by the Industry Committee on Interior Wiring Design† should be followed.

Table A-8. Conduit Sizes Required for Different Sizes and Numbers of Conductors*

(Rubber covered, types RF-32, R, RH, RW, and RU; thermoplastic, types TF, T, and TW; one to nine conductors.)

SIZE AWG MCM	NUMBER OF CONDUCTORS IN ONE CONDUIT OR TUBING								
	1	2	3	4	5	6	7	8	9
18	½	½	½	½	½	½	½	¾	¾
16	½	½	½	½	½	½	¾	¾	¾
14	½	½	½	½	¾	¾	1	1	1
12	½	½	½	¾	¾	1	1	1	1¼
10	½	¾	¾	¾	1	1	1	1¼	1¼
8	½	¾	¾	1	1¼	1¼	1¼	1½	1½
6	½	1	1	1¼	1½	1½	2	2	2
4	½	1¼	*1¼	1½	1½	2	2	2	2½
3	¾	1¼	1¼	1½	2	2	2	2½	2½
2	¾	1¼	1¼	2	2	2	2½	2½	2½
1	¾	1½	1½	2	2½	2½	2½	3	3
0	1	1½	2	2	2½	2½	3	3	3
00	1	2	2	2½	2½	3	3	3	3½
000	1	2	2	2½	3	3	3	3½	3½
0000	1¼	2	2½	3	3	3	3½	3½	4
250	1¼	2½	2½	3	3	3½	4	4	4½
300	1¼	2½	2½	3	3½	4	4	4½	4½
350	1¼	3	3	3½	3½	4	4½	4½	5
400	1½	3	3	3½	4	4	4½	5	5
500	1½	3	3	3½	4	4½	5	5	6
600	2	3½	3½	4	4½	5	6	6	6
700	2	3½	3½	4½	5	5	6	6	—
750	2	3½	3½	4½	5	6	6	6	—
800	2	3½	4	4½	5	6	6	—	—
900	2	4	4	5	6	6	6	—	—
1000	2	4	4	5	6	6	—	—	—
1250	2½	4½	4½	6	6	—	—	—	—
1500	3	5	5	6	—	—	—	—	—
1750	3	5	6	6	—	—	—	—	—
2000	3	6	6	—	—	—	—	—	—

* A neutral conductor that carries only the unbalanced current from other conductors, as in the case of normally balanced circuits of three or more conductors, shall not be counted in determining current-carrying capacities.

In a three-wire circuit consisting of two phase wires and the neutral of a four-wire, three-phase system, a common conductor carries approximately the same current as the other conductors and is not therefore considered as a neutral conductor.

Where a service run of conduit or electrical metallic tubing does not exceed 50 feet in length and does not contain more than the equivalent of two quarter bends from end to end, two No. 4 insulated and one No. 4 bare conductors may be installed in 1-inch conduit or tubing.

† Room 2650, 420 Lexington Avenue, New York, N. Y.

Table A-9. Summary of Required Electrical Outlets for Residences*

SPACE	LIGHTING OUTLETS	CONVENIENCE OUTLETS
Living room, library, den, sun room	1 Ceiling outlet, wall switch controlled; 2 outlets where room length exceeds width. Wall, cove, or valance outlets may be substituted	No point at wall line more than 6 ft from an outlet; wall spaces 3 ft or more to have outlet; outlet in mantle shelf. Two or more outlets switch controlled
Dining room, dinette, breakfast room	1 Ceiling outlet, wall switch controlled	No point at wall line more than 10 ft from an outlet; wall spaces 3 ft or more to have outlet†
Kitchen, kitchenette, pantry	1 Ceiling outlet, wall switch controlled; 1 outlet at sink, switch controlled	1 outlet for every 4 linear foot frontage of kitchen work surface. 1 outlet at refrigerator location†
Laundry	1 Ceiling outlet at washing center, 1 ceiling outlet at ironing center. Wall switch control for one ceiling outlet	
Bedrooms	1 Overhead outlet, wall switch controlled	No point at wall line more than 6 ft from an outlet. Wall spaces 3 ft or more to have outlet
Bathrooms, lavatories	1 Outlet each side mirror, wall switch controlled. 1 Ceiling outlet in shower compartment, wall switch controlled. 1 Ceiling outlet in rooms 60 sq ft and over, wall switch controlled	1 near mirror
Recreation	1 Ceiling outlet for each 150 sq ft of floor area, wall switch controlled. Wall, cove, or valance outlets may be substituted	No point at wall line more than 10 ft from an outlet; wall spaces 3 ft or more to have outlet; outlet in mantle shelf
Reception hall	1 Ceiling outlet, wall switch controlled. Wall, cove, or valance outlets may be substituted	No point at wall line more than 10 ft from an outlet; wall spaces 3 ft or more to have outlet
Halls	1 Outlet for each 15 linear feet, wall switch controlled	1 for each 15 linear feet
Stairways	1 Outlet on each floor, illuminating head, and foot of stairway. Each outlet to have separate switch control at the head and foot of stairway. Lower stairway outlet preferably controlled by three-way switches—one at foot and one at head of stairway	

Table A-9—Continued

SPACE	LIGHTING OUTLETS	CONVENIENCE OUTLETS
Closets	1 Outlet in closets 3 ft or more deep or having a floor area of 10 sq ft or more. Door switch controlled	
Exterior entrances (front and trade)	1 or 2 outlets, wall switch controlled	1 at front entrance (weatherproof)
Covered porches	1 Outlet for each 150 sq ft of porch floor, wall switch controlled	1 for each 15 linear feet of house wall bordering porch
Terraces and patios		1 for each 15 linear feet of house wall bordering porch (weatherproof)
Basement utility space	1 Outlet for each enclosed space, 1 for work bench, and 1 for furnace location. Sufficient additional outlets to provide 1 for each 150 sq ft of open space	1 at work bench location, 1 at furnace location
Accessible attics	1 Outlet, wall switch controlled. 1 outlet for each enclosed space	1 for general use
Garage	1 Interior wall switched outlet for one- or two-car garage, plus 1 for each additional two cars. 1 Outlet for exterior lighting, multiple-switch controlled if garage is detached from house	1 for one- or two-car garage, plus 1 for each additional two cars.

* All outlets supplied by general-purpose circuits except as noted by†.
A convenience outlet shall be at least of the duplex type (two or more plug-in positions), except as otherwise specified.
All spaces for which wall-switch controls are required, and which have more than one principal entrance, shall be equipped with multiple-switch control at the lock side of doors, or the traffic side of arches. If this requirement would result in the placing of switches that control the same light within 10 ft of each other, one of the switch locations may be eliminated.
† Supplied by appliance circuit.

EXTERIOR WIRING

The principles of interior wiring in general will apply equally well for exterior wiring. The problems of capacity, voltage drop, etc., should be calculated carefully in order to ensure proper utilization voltage and system operation. The National Electrical Code recognizes the special problems of "Outside Wiring" in Article 730.

Wiring Methods

Where wiring is run underground, in concrete walls, or on the exterior of buildings, rigid conduit generally is used. All outlets and switches must be installed in

weatherproof fittings, usually with threaded cast-iron hubs to make water-tight joints. For some systems fiber or cement-asbestos conduit, either buried direct in ground or encased in concrete, is used instead of steel conduit. Open overhead wiring is widely used principally for reasons of economy. All conductors used for overhead wiring should have type WP insulation. The current-carrying capacities are greater for conductors in air, because of better heat dissipation. Various wiring methods are listed below with their most common applications:

Open conductors on insulators	Flood lighting Festoon lighting Advertising spot lighting Highway lighting
Rigid steel conduit	Bridges, tunnels, and underpasses Street lighting Traffic signals Flood lighting
Fiber conduit: Class I in concrete Class II direct burial	Street lighting
Parkway cables: Nonmetallic sheathed cable	Street lighting Airport lighting
Steel-taped sheathed cable	Flood lighting

Wiring for Bridge, Tunnel, and Underpass Lighting

For bridges, tunnels, and underpasses, wiring fixtures are the weatherproof type with guards and wires generally run in conduit. All wires installed in these conduits should have moisture-resisting insulation type RW, TW, or rubber and lead sheathed. On bridges considerations should be given to vibration and all long vertical runs should have the conductors supported at frequent intervals in junction boxes. Where it is impractical to drain a conduit to the junction box, special drainage provisions should be made at low points.

Wiring for Floodlighting and Sign Lighting

Floodlighting and sign lighting frequently are installed with open wiring. Floodlights are mounted on crossarms or poles and often are arranged with bushing-type terminals to connect to open wires. The principal problems of this type of wiring are clearances between wires, buildings, and other obstructions, and because of the long runs frequently encountered, maintainance of proper socket voltage. The matter of safe clearances is well defined in Article 730 of the National Electrical Code and Part 2 of the National Electrical Safety Code. Wire size should be large enough to ensure proper utilization voltage, which in sports lighting sometimes is specified as 10 per cent over normal. (See Section 12.)

High-wattage floodlights may require separate circuits. In automobile parking lots and on buildings rigid conduit systems generally are required. A parking lot usually will have conduits run underground to floodlight standards. These standards are often steel pipe, and underground conduits terminate just above ground level in the standard. Signs often are so constructed that conduit can terminate directly in the body of the sign. Some signs have complete fuse panels built into the sign body and only a feeder of proper capacity is required to the sign. Care should be taken to adhere to the provisions of Article 600 of the National Electrical Code which requires

an externally-operable switch within sight of sign or outline lighting. This is a safety feature to protect men working on the sign. The other provisions of this Article follow in general the rules for any conduit system. Today outdoor Christmas-tree or similar holiday decorative lighting is the only common application of festoon or incandescent outline lighting. Most of these installations are temporary and are used for a short time only. Therefore the design requirements for permanent installations are not followed.

Wiring for Street and Highway Lighting

Two wiring methods are used to supply power for street and highway lighting:

1. Overhead lines for highway and suburban streets.

2. Underground lines for ornamental street lighting, used for higher levels of illumination in business districts and bridges. Multiple and series systems are applicable to both classifications.

Overhead wiring. Wire used for overhead systems generally is No. 6 solid copper conductor. Here, current-carrying capacity is not the principal criterion by which the wire is chosen, as a conductor of smaller cross section generally would transmit the current without economic waste. Since current-carrying capacity is not the question of primary interest, it is generally accepted practice to use a wire size that will obtain the best compromise between first cost and sufficient tensile strength to hold up under adverse conditions. Where wider pole spacing is desirable, No. 6 copper-clad steel wire has been used with considerable success.

The standard insulation, regardless of voltage, has been triple braid weatherproof. Insulation is provided by means of porcelain or glass insulators on the poles and in luminaires. The spacing of conductors and clearance to ground is specifically covered in the National Electrical Safety Code.

Underground wiring. There are three approved types of underground conductors:

(1) *Rigid steel conduit* is used for all small installations because materials and installation skill are available. This material also is used in combination with the other methods. For example, where direct-burial cables cross streets iron pipe is installed so that if necessary this section can be replaced without tearing up the street.

(2) *Fiber duct* or *cement-asbestos duct* is used interchangeably, depending on conditions and individual preference. Two types of duct are available, one with heavy walls for direct burial in ground and one with light walls for encasement in a concrete envelope. The duct in concrete is the most permanent type and a requirement in many cities. It often is installed in banks of ducts which carry power circuits. The duct for direct burial without envelope is growing in use, and is more economical to install.

The conductor type is the same in both ducts, either moisture resistant rubber, synthetic compounds, or rubber with lead sheath. The insulation will vary also according to the operating voltage of the system. The advantages of the duct for underground systems over parkway cable is the same as the advantages of conduit over nonmetallic sheathed cable or BX cable in building wiring. The duct is a somewhat more expensive installation than buried cable, but has the advantages of easier replacement should defects develop.

(3) *Parkway cables* are manufactured in many types, from rubber-covered, lead-sheathed, and steel-taped to synthetic insulation for direct burial. Cable in this form gives satisfactory performance except for the hazard of mechanical injury. The steel tape offers some protection but occasionally a rock or other sharp object is pressed through the steel tape causing a break-down in the system. Where difficulty has been encountered with underground cable installations, it often may be traced to lack of care in laying. Lead-sheathed or armored cable cannot be bent on a small radius without injury. Connection to other wires should be brought well up into the base of the standard so as to guard against the entrance of moisture.

Series Circuits for Street Lighting

Series circuits for street lighting have been predominate in the past for three reasons: 1. When electric street lighting was first introduced it was almost entirely arc lighting. The arc lamp is inherently a constant-current device and consequently gives its best operation and greatest efficiency on the constant-current series circuit. 2. In many areas, the street lighting antedated the general use of electricity in homes by a considerable period; the series circuit is the most simple and efficient method of supplying energy to comparatively small units sparsely located over a wide area. 3. A separate system of distribution furnishes a convenient means of control from the central station.

The advantages of the series system are as follow:

1. In the smaller sizes, incandescent lamps for series service are more efficient than the multiple lamps. In all sizes, lamps operated on constant-current circuits have better light-output maintenance characteristics.

2. The rated life of series lamps is about one-third longer than that of comparable multiple lamps.

3. The smaller sizes of series lamps are more rugged than the multiple type.

4. The filament in a series lamp approximates more closely a point light source and therefore the light may be controlled more accurately.

5. Since series lamps are rated in lumen output, this allows contracts with cities to be made on a fixed output basis.

6. A properly installed series circuit affords freedom from voltage variations and voltage drop.

Multiple Circuits for Street Lighting

Multiple circuits for street lighting are gaining in favor primarily because of greater economies in installation. With the high density of transformers and low-voltage networks now found in the modern city, short secondaries can be obtained at most any point. The advantages of this type of circuit are as follows:

1. In the larger sizes the multiple lamps are slightly more efficient than even the high-current series lamps. A greater differential in favor of the multiple lamps is shown when the series lamps are charged with a loss of about 7 per cent occurring in their individual transformers.

2. The flexibility of the multiple distribution permits the easy addition of more lamps or the substitution of larger lamps.

3. The transforming equipment and fixtures are simpler and lower in cost.

4. There is pressing need for central station space now occupied by special transformers and for ducts now filled with series cables.

5. A duplicate distribution system is eliminated.

6. The load factor of existing multiple circuits is improved.

7. Multiple lamps are less expensive to manufacture and, therefore, are lower in cost.

8. The possibility of simultaneous burning out of large numbers of lamps is eliminated.

9. The use of mercury and sodium lamps requires transformers to provide the higher voltage necessary to start. On series systems this requires excess regulator capacity which results in higher installation cost. With most discharge-type lamps, starting equipment is required. The constant-voltage multiple circuit is the most economical arrangement for this operation.

10. Because of operation at lower voltages, cable cost and installation are less expensive.

The multiple-circuit installation then becomes a typical installation as outlined for other types of lighting. For protection of the individual street-lighting standards a fuse frequently is installed in the base, in the space usually taken by series cutouts or transformer equipment. All wiring in run with standard 600-volt insulated wire, which is available in many types and sizes.

PROCEDURE FOR OBTAINING I. C. I. SPECIFICATIONS FROM SPECTROPHOTOMETRIC CURVES

Problem

Having the spectral reflectance curve (Fig. 4–9) for a deep red surface specified R 4/14 in Munsell notation, express its specification, when illuminated by I. C. I. Illuminant *C* (average daylight), in I. C. I. co-ordinates x, y, and Y.

Solution by Weighted Ordinate Method*

Step 1. Tabulate as in Column I of Table A-10 the wavelengths in 0.01-micron steps between 0.38 and 0.76 inclusive. In column II list the corresponding spectral reflectance (r_λ) values for R 4/14 obtained from Fig. 4–9. In Column III tabulate the I. C. I. tristimulus computational data $\bar{x}P$, $P\bar{y}$, $\bar{z}P$ for Illuminant C from Table A-11.

Step 2. Multiply the tristimulus factors at each wavelength by the corresponding value of r_λ and tabulate each result under $\bar{x}Pr_\lambda$, $\bar{y}Pr_\lambda$, and $\bar{z}Pr_\lambda$ in column IV.

Step 3. Obtain separately the sums of the three columns $\bar{x}Pr_\lambda$, $\bar{y}Pr_\lambda$, and $\bar{z}Pr_\lambda$. These equal X, Y, and Z, respectively, for the R 4/14 sample as it appears when under Illuminant C to the I. C. I. standard observer.

Step 4. Solve for x and y by substituting values in the equations:

$$x = \frac{X}{X+Y+Z} = 0.56 \qquad y = \frac{Y}{X+Y+Z} = 0.31 \qquad Y = \frac{\Sigma\bar{y}Pr_\lambda}{\Sigma\bar{y}P} = \frac{13{,}337}{100{,}000} = 0.13$$

The I. C. I. specification for R 4/14 is $x = 0.56$, $y = 0.31$, $Y = 0.13$.

If it is desired to obtain the co-ordinates for a source whose $\bar{x}P$, $\bar{y}P$, and $\bar{z}P$ factors are not already computed, the factors may be obtained by multiplying the spectral energy emitted by the source at each wavelength by the amounts of the I. C. I. primaries required by the standard observer to match equal energy at each wavelength. These amounts are given in Fig. 4-16. To make a more convenient table each term is multiplied by a suitable factor so that the sum of the $\bar{y}P$ column is 100,000. When many calculations are to be made, I.B.M. machines can be used.

Solution by Selected Ordinate Method

By selecting certain ordinates (different for each illuminant), the procedure for obtaining trichromatic coordinates can be simplified considerably:

Step 1. Tabulate under X, Y, and Z, as in Table A-12, the spectral reflectance of $R4/14$ (from Table A-10) for each of the 10 (or 30) selected ordinates for Illuminant C found in Table A-13.

Step 2. Obtain the sums of columns X, Y, and Z, respectively.

Step 3. To obtain X, Y, and Z for the red sample R 4/14, multiply each sum by the *column factor*, from Table A-13, for the number of ordinates used.

When the number of ordinates used is 10

$$\begin{cases} X = 0.09804 \times 2.465 = 0.24 \\ Y = 0.1 \times 1.318 \quad\;\; = 0.13 \\ Z = 0.11812 \times 0.465 = 0.06 \end{cases}$$

Step 4.

$$x = \frac{X}{X+Y+Z} = 0.56 \qquad y = \frac{Y}{X+Y+Z} = 0.31 \qquad \text{Reflectance} = Y = 0.13$$

Same as by more tedious method above.

Mechanical integrators eliminate almost all of the numerical work of the selected ordinate method. It is necessary that the integrator scales fit the paper on which the curves are plotted.

It should be noted that a more irregular curve would require use of a greater number of ordinates for equal accuaracy.

* A. C. Hardy, *Handbook of Colorimetry*, The Technology Press, Massachusetts Institute of Technology, Cambridge, Massachusetts, 1936.

TABLE A-10. Determination from Spectrophotometric Curve of I.C.I. Co-ordinates for a Surface Illuminated by Illuminant C

I WAVE-LENGTH (microns)	II REFLECT-ANCE R 4/14 r_λ (from Fig. 4-9)	III I.C I. DATA FOR ILLUMINANT C (from Table A-11)			IV (II × III)		
		$\bar{x}P$	$\bar{y}P$	$\bar{z}P$	$\bar{x}P\ r_\lambda$	$\bar{y}P_\lambda$	$\bar{z}P_\lambda$
0.380	0.051	4		20			1
.390	.051	19		89	1		5
.400	.051	85	2	404	4		21
.410	.051	329	9	1,570	17		80
.420	.050	1,238	37	5,949	62	2	297
.430	.050	2,997	122	14,628	150	6	731
.440	.050	3,975	262	19,938	199	13	997
.450	.047	3,915	443	20,638	184	21	970
.460	.045	3,362	694	19,299	151	31	868
.470	.044	2,272	1,058	14,972	100	47	659
.480	.043	1,112	1,618	9,461	48	70	407
.490	.041	363	2,358	5,274	15	97	216
.500	.041	52	3,401	2,864	2	139	117
.510	.041	89	4,833	1,520	4	198	62
.520	.041	576	6,462	712	24	265	29
.530	.041	1,523	7,934	388	62	325	16
.540	.041	2,785	9,149	195	114	375	8
.550	.042	4,282	9,832	86	180	413	4
.560	.043	5,880	9,841	39	253	423	2
.570	.050	7,322	9,147	20	366	457	1
.580	.075	8,417	7,992	16	631	599	1
.590	.145	8,984	6,627	10	1,303	961	1
.600	.290	8,949	5,316	7	2,595	1,542	2
.610	.465	8,325	4,176	2	3,871	1,942	1
.620	.575	7,070	3,153	2	4,065	1,813	1
.630	.623	5,309	2,190		3,308	1,364	
.640	.648	3,693	1,443		2,393	935	
.650	.667	2,349	886		1,567	591	
.660	.683	1,361	504		930	344	
.670	.699	708	259		495	181	
.680	.713	369	134		263	96	
.690	.725	171	62		124	45	
.700	.739	82	29		61	21	
.710	.749	39	14		29	10	
.720	.762	19	6		14	5	
.730	.775	8	3		6	2	
.740	.785	4	2		3	2	
.750	.791	2	1		2	1	
.760	.795	1	1		1	1	
Sums.....		98,040	100,000	118,103	X = 23,597	Y = 13,337	Z = 5,497

Table A-11. I.C.I. Tristimulus Computational Data for Several Illuminants Computed for the I.C.I. Standard Observer

WAVE-LENGTH (microns)	I.C.I. STANDARD ILLUMINANT A (Planck 2,850 K, c_2 = 1.436)			I.C.I. STANDARD ILLUMINANT B		
	$\bar{x}P$	$\bar{y}P$	$\bar{z}P$	$\bar{x}P$	$\bar{y}P$	$\bar{z}P$
0.38	1		6	3		14
.39	5		23	13		60
.40	19	1	93	56	2	268
.41	71	2	340	217	6	1,033
.42	262	8	1,256	812	24	3,899
.43	649	27	3,167	1,983	81	9,678
.44	926	61	4,647	2,689	178	13,489
.45	1,031	117	5,435	2,744	310	14,462
.46	1,019	210	5,851	2,454	506	14,085
.47	776	362	5,116	1,718	800	11,319
.48	428	622	3,636	870	1,265	7,396
.49	160	1,039	2,324	295	1,918	4,290
.50	27	1,792	1,509	44	2,908	2,449
.51	57	3,080	969	81	4,360	1,371
.52	425	4,771	525	541	6,072	669
.53	1,214	6,322	309	1,458	7,594	372
.54	2,313	7,600	162	2,689	8,834	188
.55	3,732	8,568	75	4,183	9,603	84
.56	5,510	9,222	36	5,840	9,774	38
.57	7,571	9,457	21	7,472	9,334	21
.58	9,719	9,228	18	8,843	8,396	16
.59	11,579	8,540	12	9,728	7,176	10
.60	12,704	7,547	10	9,948	5,909	7
.61	12,669	6,356	4	9,436	4,734	3
.62	11,373	5,071	3	8,140	3,630	2
.63	8,980	3,704		6,200	2,558	
.64	6,558	2,562		4,374	1,709	
.65	4,336	1,637		2,815	1,062	
.66	2,628	972		1,655	612	
.67	1,448	530		876	321	
.68	804	292		465	169	
.69	404	146		220	80	
.70	209	75		108	39	
.71	110	40		53	19	
.72	57	19		26	9	
.73	28	10		12	4	
.74	11	6		6	2	
.75	6	2		2	1	
.76	4	2		2	1	
.77	2			1		
Total.....	109,828	100,000	35,547	99,072	100,000	85,223
	x = 0.4476 y = 0.4075			x = 0.3485 y = 0.3518		

Table A-11—Continued

WAVE-LENGTH (microns)	I.C.I. STANDARD ILLUMINANT C			ILLUMINANT "S" (Limit Blue Sky—Gibson)		
	$\bar{x}P$	$\bar{y}P$	$\bar{z}P$	$\bar{x}P$	$\bar{y}P$	$\bar{z}P$
.38	4		20	36		165
.39	19		89	99	3	473
.40	85	2	404	349	10	1,658
.41	329	9	1,570	1,199	33	5,719
.42	1,238	37	5,949	3,567	107	17,137
.43	2,997	122	14,628	6,852	280	33,442
.44	3,975	262	19,938	8,143	538	40,845
.45	3,915	443	20,638	7,652	865	40,332
.46	3,362	694	19,299	6,194	1,278	35,554
.47	2,272	1,058	14,972	3,870	1,803	25,503
.48	1,112	1,618	9,461	1,742	2,533	14,815
.49	363	2,358	5,274	530	3,444	7,703
.50	52	3,401	2,864	74	4,871	4,102
.51	89	4,833	1,520	127	6,870	2,160
.52	576	6,462	712	781	8,757	965
.53	1,523	7,934	388	1,847	9,618	471
.54	2,785	9,149	195	2,958	9,717	207
.55	4,282	9,832	86	4,070	9,343	81
.56	5,880	9,841	39	5,148	8,615	34
.57	7,322	9,147	20	6,092	7,610	16
.58	8,417	7,992	16	6,798	6,454	13
.59	8,984	6,627	10	7,090	5,229	7
.60	8,949	5,316	7	6,798	4,039	5
.61	8,325	4,176	2	5,871	2,945	2
.62	7,070	3,153	2	4,585	2,044	1
.63	5,309	2,190		3,160	1,303	
.64	3,693	1,443		2,030	793	
.65	2,349	886		1,183	447	
.66	1,361	504		636	236	
.67	708	259		313	114	
.68	369	134		155	56	
.69	171	62		69	25	
.70	82	29		32	11	
.71	39	14		15	5	
.72	19	6		7	3	
.73	8	3		3	1	
.74	4	2		2	1	
.75	2	1				
.76	1	1		1		
.77	1					
Total.....	98,041	100,000	118,103	100,078	100,000	231,410
	$x = 0.3101$ $y = 0.3163$			$x = 0.23194$ $y = 0.23176$		

Table A-12. Determination of I.C.I. Coordinates for R4/14 (Illuminant C) by Selected Ordinate Method

SELECTED ORDINATE NUMBER (From Table A 13)	REFLECTANCE OF R 4/14 Selected Ordinates)		
	X	Y	Z
1	0.050	0.041	0.050
2	.045	.041	.050
3	.042	.041	.050
4	.046	.041	.049
5	.061	.042	.047
6	.038	.044	.046
7	.275	.055	.045
8	.553	.103	.044
9	.595	.300	.043
10	.660	.610	.041
SUMS.....	2.465	1.318	.465

Table A-13. Selected ordinates for Illuminants A, B, and C

ORDINATE NUMBER		ILLUMINANT A			ILLUMINANT B			ILLUMINANT C		
		X	Y	Z	X	Y	Z	X	Y	Z
	1	444.0	487.8	416.4	428.1	472.3	414.8	424.4	465.9	414.1
1	2	516.9	507.7	424.9	442.1	494.5	422.9	435.5	489.4	422.2
	3	544.0	517.3	429.4	454.1	505.7	427.1	443.9	500.4	426.3
	4	554.2	524.1	432.9	468.1	513.5	430.3	452.1	508.7	429.4
2	5	561.4	529.8	436.0	527.8	519.6	433.0	461.2	515.1	432.0
	6	567.1	534.8	438.7	543.3	524.8	435.4	474.0	520.6	434.3
	7	572.0	539.4	441.3	551.9	529.4	437.7	531.2	525.4	436.5
3	8	576.3	543.7	443.7	558.5	533.7	439.9	544.3	529.8	438.6
	9	580.2	547.8	446.0	564.0	537.7	442.0	552.4	533.9	440.6
	10	583.9	551.7	448.3	568.8	541.5	444.0	558.7	537.7	442.5
4	11	587.2	555.4	450.5	573.1	545.1	446.0	564.1	541.4	444.4
	12	590.5	559.1	452.6	577.1	548.7	448.0	568.9	544.9	446.3
	13	593.5	562.7	454.7	580.9	552.1	450.0	573.2	548.4	448.2
5	14	596.5	566.3	456.8	584.5	555.5	451.9	577.3	551.8	450.1
	15	599.4	569.8	458.8	588.0	559.0	453.9	581.3	555.1	452.1
	16	602.3	573.3	460.8	591.4	562.4	455.8	585.0	558.5	454.0
6	17	605.2	576.9	462.9	594.7	565.8	457.8	588.7	561.9	455.9
	18	608.0	580.5	464.9	598.1	569.3	459.8	592.4	565.3	457.9
	19	610.9	584.1	467.0	601.4	572.9	461.8	596.0	568.9	459.9
7	20	613.8	587.9	469.2	604.7	576.7	463.9	599.6	572.5	462.0
	21	616.9	591.8	471.6	608.1	580.6	466.1	603.3	576.4	464.1
	22	620.0	595.9	474.1	611.6	584.7	468.4	607.0	580.5	466.3
8	23	623.3	600.1	476.8	615.3	589.1	470.8	610.9	584.8	468.7
	24	626.9	604.7	479.9	619.1	593.9	473.6	615.0	589.6	471.4
	25	630.8	609.7	483.4	623.3	599.1	476.6	619.4	594.8	474.3
9	26	635.3	615.2	487.5	628.0	605.0	480.2	624.2	600.8	477.7
	27	640.5	621.5	492.7	633.4	611.8	484.5	629.8	607.7	481.8
	28	646.9	629.2	499.3	640.1	619.9	490.2	636.6	616.1	487.2
10	29	655.9	639.7	508.4	649.2	630.9	498.6	645.9	627.3	495.2
	30	673.5	659.0	526.7	666.3	650.7	515.2	663.0	647.4	511.2
		COLUMN FACTORS FOR 30 ORDINATES								
30 ordinates.....		0.03661	0.03333	0.01185	0.03303	0.03333	0.02842	0.03268	0.03333	0.03938
		COLUMN FACTORS FOR 10 ORDINATES								
10 ordinates.....		0.10984	0.10000	0.03555	0.09908	0.10000	0.08526	0.09804	0.10000	0.11814

Table A-14. Central Munsell Notations for Each I.S.C.C.-N.B.S. Color-Name Block

NAME	MUNSELL NOTATION OF CENTRAL COLOR		NAME	MUNSELL NOTATION OF CENTRAL COLOR	
GRAYS AND NEAR GRAYS:			weak purplish pink	4.5RP	7.0/3.0
white	N	9.2/	moderate purplish pink	4.5RP	7.0/7.0
light gray	N	7.5/	strong purplish pink	4.5RP	7.0/11.0
medium gray	N	5.5/			
dark gray	N	3.5/	pale pink	2.0R	8.7/2.8
black	N	1.3/	light pink	3.0R	8.7/6.2
			brilliant pink	0.5R	8.5/11.0
pinkish white	6.5R	9.0/1.0			
pinkish gray	6.5R	7.5/1.0	weak pink	3.5R	7.3/2.5
reddish gray	8.5R	5.5/1.0	moderate pink	4.5R	7.3/5.7
dark reddish gray	7.5R	3.5/1.0	strong pink	4.5R	7.8/9.7
reddish black	7.5R	1.5/1.0	vivid pink	6.0R	8.2/13.0
light brownish gray	8.5YR	5.5/1.0	pale orange pink	2.5YR	9.0/2.0
brownish gray	7.5YR	3.5/1.0	light orange pink	2.0YR	9.0/4.8
brownish black	7.5YR	1.5/1.0			
			weak orange pink	2.5YR	7.7/2.0
yellowish white	7.5Y	9.0/1.1	moderate orange pink	2.0YR	7.5/4.8
yellowish gray	7.5Y	7.5/1.1	strong orange pink	1.5YR	8.5/9.0
light olive gray	9.5Y	5.5/1.1			
olive gray	9.5Y	3.5/1.1	pale purplish red	0.5R	6.0/4.0
olive black	9.5Y	1.5/1.1	light purplish red	0.5R	6.0/8.0
			brilliant purplish red	0.5R	6.0/12.0
greenish white	5.5G	9.0/1.0			
light greenish gray	5.5G	7.5/1.0	weak purplish red	0.5R	4.5/4.0
medium greenish gray	5.5G	5.5/1.0	moderate purplish red	0.5R	4.5/7.0
dark greenish gray	5.5G	3.5/1.0	strong purplish red	0.5R	4.5/11.0
greenish black	5.5G	1.5/1.0	vivid purplish red	0.5R	4.5/14.0
bluish white	6.0B	9.0/1.0	dusky purplish red	0.5R	3.0/4.0
light bluish gray	6.0B	7.5/1.0	dark purplish red	0.5R	3.0/7.0
medium bluish gray	6.0B	5.5/1.0	deep purplish red	0.5R	3.0/11.0
dark bluish gray	6.0B	3.5/1.0			
bluish black	6.0B	1.5/1.0	very dusky purplish red	0.5R	1.5/4.0
			very dark purplish red	0.5R	1.5/7.0
purplish white	6.0P	9.0/1.0	very deep purplish red	0.5R	1.5/11.0
light purplish gray	6.0P	7.5/1.0			
			pale red	8.5R	6.0/2.7
medium purplish gray	0.5RP	9.0/1.0	light red	5.0R	6.0/8.0
dark purplish gray	0.5RP	3.5/1.0	brilliant red	5.0R	6.0/12.0
purplish black	0.5RP	1.5/1.0			
			weak red	8.5R	4.5/2.7
PINKS AND REDS:			moderate red	5.0R	4.5/7.0
pinkish white	6.5R	9.0/1.0	strong red	5.0R	4.5/11.0
pinkish gray	6.5R	7.5/1.0	vivid red	5.0R	4.5/14.0
reddish gray	8.5R	5.5/1.0			
dark reddish gray	7.5R	3.5/1.0	dusky red	8.5R	3.0/2.6
reddish black	7.5R	1.5/1.0	dark red	5.0R	3.0/7.0
pale purplish pink	4.5RP	8.7/3.0			
light purplish pink	4.5RP	8.5/7.0			
brilliant purplish pink	4.5RP	8.5/11.0			

Table A-14—Continued

NAME	MUNSELL NOTATION OF CENTRAL COLOR	
deep red	5.0R	2.5/11.0
very dusky red	8.5R	1.5/2.6
very dark red	5.0R	1.5/7.0
ORANGES AND BROWNS:		
light brownish gray	8.5YR	5.5/1.0
brownish gray	7.5YR	3.5/1.0
brownish black	7.5YR	1.5/1.0
light reddish orange	9.0R	7.0/9.0
brilliant reddish orange	9.0R	7.0/13.0
weak reddish orange	9.5R	5.7/5.5
moderate reddish orange	9.0R	5.5/9.0
strong reddish orange	9.0R	5.5/13.0
vivid reddish orange	9.0R	5.5/16.0
dark reddish orange	9.0R	4.0/10.0
deep reddish orange	9.0R	4.0/13.0
very pale orange	9.0YR	8.5/2.0
pale orange	6.5YR	8.5/5.0
light orange	5.5YR	8.5/9.0
brilliant orange	5.5YR	8.5/13.0
weak orange	5.5YR	6.6/5.4
moderate orange	4.5YR	6.5/9.0
strong orange	4.5YR	6.5/13.0
vivid orange	4.5YR	6.2/16.0
dark orange	4.5YR	5.0/9.0
deep orange	4.5YR	5.0/13.0
pale yellowish orange	0.5Y	9.0/5.1
light yellowish orange	10.0YR	9.0/9.0
brilliant yellowish orange	10.0YR	9.0/13.0
weak yellowish orange	0.5Y	7.5/5.1
moderate yellowish orange	10.0YR	7.5/9.0
strong yellowish orange	10.0YR	7.5/13.0
vivid yellowish orange	10.0YR	7.5/16.0
dusky yellowish orange	10.0YR	6.0/6.0
dark yellowish orange	10.0YR	6.0/9.0
deep yellowish orange	10.0YR	6.0/13.0
pale reddish brown	1.5YR	5.0/4.0
weak reddish brown	1.5YR	3.5/4.0
moderate reddish brown	9.0R	3.5/7.0
strong reddish brown	9.0R	3.0/11.0
dusky reddish brown	1.5YR	1.5/4.0
dark reddish brown	9.0R	1.5/7.0
deep reddish brown	9.0R	1.5/11.0
very pale brown	9.0YR	7.0/2.0
pale brown	8.5YR	5.5/2.0
light brown	5.0YR	5.3/5.0
weak brown	8.5YR	3.5/2.0
moderate brown	5.0YR	3.5/5.0
strong brown	4.5YR	3.5/9.0
dusky brown	8.5YR	1.5/2.0
dark brown	5.0YR	1.5/5.0
deep brown	4.5YR	1.5/9.0
light yellowish brown	1.0Y	6.0/4.0
moderate yellowish brown	10.0YR	4.5/5.2
strong yellowish brown	10.0YR	4.5/9.0
dark yellowish brown	10.0YR	2.5/5.2
deep yellowish brown	10.0YR	2.5/9.0
light olive brown	4.0Y	5.0/5.0
moderate olive brown	4.0Y	3.5/5.0
dark olive brown	4.0Y	1.5/5.0
YELLOWS AND OLIVES:		
yellowish white	7.5Y	9.0/1.1
yellowish gray	7.5Y	7.5/1.1
light olive gray	9.5Y	5.5/1.1
olive gray	9.5Y	3.5/1.1

Table A-14—Continued

NAME	MUNSELL NOTATION OF CENTRAL COLOR		NAME	MUNSELL NOTATION OF CENTRAL COLOR	
olive black	9.5Y	1.5/1.1	dusky olive green	4.0GY	1.5/2.0
			dark olive green	4.0GY	1.5/5.0
pale yellow	5.5Y	9.0/3.3	deep olive green	4.0GY	1.5/9.0
light yellow	4.5Y	9.0/7.0			
brilliant yellow	4.5Y	9.0/11.0	pale yellow green	4.0GY	8.5/2.5
			light yellow green	4.0GY	8.5/7.0
weak yellow	5.5Y	7.5/3.3	brilliant yellow green	4.0GY	8.5/11.0
moderate yellow	4.5Y	7.5/7.0			
strong yellow	4.5Y	7.5/11.0			
vivid yellow	4.5Y	7.5/14.0	weak yellow green	4.0GY	6.5/2.5
			moderate yellow green	4.0GY	6.5/7.0
dusky yellow	5.0Y	6.0/4.0	strong yellow green	4.0GY	6.5/11.0
dark yellow	4.5Y	6.0/7.0	vivid yellow green	4.0GY	6.5/14.0
deep yellow	4.5Y	6.0/11.0			
			dusky yellow green	4.0GY	5.0/2.5
pale greenish yellow	9.0Y	9.0/4.0	dark yellow green	4.0GY	4.5/7.0
light greenish yellow	9.0Y	9.0/7.0	deep yellow green	4.0GY	4.5/11.0
brilliant greenish yellow	9.0Y	9.0/11.0			
			very pale yellowish green	9.5GY	9.0/4.0
weak greenish yellow	9.0Y	7.5/4.0	very light yellowish green	9.5GY	9.0/7.0
moderate greenish yellow	9.0Y	7.5/7.0			
strong greenish yellow	9.0Y	7.5/11.0	pale yellowish green	9.5GY	7.5/4.0
vivid greenish yellow	9.0Y	7.5/14.0	light yellowish green	9.5GY	7.5/7.0
			brilliant yellowish green	9.5GY	5.5/11.0
dusky greenish yellow	9.0Y	6.0/4.0	vivid yellowish green	9.5GY	6.5/14.0
dark greenish yellow	9.0Y	6.0/7.0			
deep greenish yellow	9.0Y	6.0/11.0	dark yellowish green	9.5GY	4.0/5.0
			deep yellowish green	9.5GY	4.0/9.0
pale olive	6.0Y	5.5/2.5			
light olive	8.5Y	5.0/5.0	very dark yellowish green	9.5GY	2.5/5.0
weak olive	6.0Y	3.5/2.5	very deep yellowish green	9.5GY	2.5/9.0
moderate olive	8.5Y	3.5/5.0			
			very pale green	2.5G	8.5/2.0
dusky olive	6.0Y	1.5/2.5	very light green	5.5G	8.5/5.2
dark olive	8.5Y	1.5/5.0	very brilliant green	6.0G	8.5/9.0
GREENS:					
greenish white	5.5G	9.0/1.0	pale green	2.5G	6.5/2.0
light greenish gray	5.5G	7.5/1.0	light green	5.5G	6.5/5.2
medium greenish gray	5.5G	5.5/1.0	brilliant green	6.0G	6.5/9.0
dark greenish gray	5.5G	3.5/1.0			
greenish black	5.5G	1.5/1.0			
			weak green	2.5G	4.5/2.0
weak olive green	4.0GY	3.5/2.0	moderate green	5.5G	4.5/5.2
moderate olive green	4.0GY	3.3/4.7	strong green	6.0G	4.5/9.0
strong olive green	4.0GY	3.0/9.0	vivid green	6.0G	5.5/12.0

Table A-14—Continued

NAME	MUNSELL NOTATION OF CENTRAL COLOR		NAME	MUNSELL NOTATION OF CENTRAL COLOR	
dusky green	6.0G	3.0/2.0	ish blue	1.0B	8.5/5.0
dark green	5.5G	3.0/5.2			
deep green	6.0G	2.5/9.0	light greenish blue	1.0B	6.5/5.0
very dusky green	6.0G	1.5/2.0	brilliant greenish blue	1.0B	7.0/9.0
very dark green	5.5G	1.5/5.2	moderate greenish blue	1.0B	4.5/5.0
very light bluish green	10.0G	8.5/4.8	strong greenish blue	1.0B	4.5/9.0
light bluish green	10.0G	6.5/4.8	vivid greenish blue	1.0B	4.5/12.0
brilliant bluish green	1.0BG	7.2/9.0	dark greenish blue	1.0B	3.0/5.0
moderate bluish green	10.0G	4.5/4.8	deep greenish blue	1.0B	2.5/9.0
strong bluish green	1.0BG	4.5/9.0	very dark greenish blue	1.0B	1.5/5.0
vivid bluish green	1.0BG	4.5/12.0			
dark bluish green	10.0G	3.0/4.8	very pale blue	6.5B	8.5/2.9
deep bluish green	10.0BG	2.5/9.0	very light blue	8.5B	8.5/7.0
			very brilliant blue	8.5B	8.5/11.0
very dark bluish green	10.0G	1.5/4.8	pale blue	6.5B	6.5/2.9
			light blue	8.5B	6.5/7.0
very pale blue green	2.0BG	8.5/2.0	brilliant blue	8.5B	6.5/11.0
very light blue green	5.5BG	8.5/5.0	weak blue	6.5B	4.5/2.9
			moderate blue	8.5B	4.5/7.0
			strong blue	8.5B	4.5/11.0
pale blue green	2.0BG	6.5/2.0	vivid blue	8.5B	4.5/14.0
light blue green	4.4BG	6.5/5.0			
brilliant blue green	5.5BG	7.0/9.0	dusky blue	8.0B	2.5/3.1
			dark blue	8.5B	2.5/7.0
			deep blue	8.5B	2.5/11.0
weak blue green	2.0BG	4.5/2.0			
moderate blue green	5.5BG	4.5/5.0	very pale purplish blue	6.0PB	8.0/2.6
strong blue green	5.5BG	4.5/9.0	very light purplish blue	5.5PB	7.5/7.0
vivid blue green	5.5BG	4.5/12.0			
			very brilliant purplish blue	5.5PB	7.5/11.0
dusky blue green	8.0BG	3.0/2.0			
dark blue green	5.5BG	3.0/5.0			
deep blue green	5.5BG	2.5/9.0	pale purplish blue	6.0PB	5.5/2.6
			light purplish blue	5.5PB	5.5/7.0
very dusky blue green	8.0BG	1.5/2.0	brilliant purplish blue	5.5PB	5.5/11.0
very dark blue green	5.5BG	1.5/5.0			
			weak purplish blue	6.0PB	3.5/2.6
BLUES:					
bluish white	6.0B	9.0/1.0	moderate purplish blue	5.5PB	3.5/7.0
light bluish gray	6.0B	7.5/1.0			
medium bluish gray	6.0B	5.5/1.0	strong purplish blue	5.5PB	3.5/11.0
dark bluish gray	6.0B	3.5/1.0	vivid purplish blue	5.5PB	4.5/15.0
bluish black	6.0B	1.5/1.0			

Table A-14—Continued

NAME	MUNSELL NOTATION OF CENTRAL COLOR		NAME	MUNSELL NOTATION OF CENTRAL COLOR	
very light green-blue	6.0PB	1.5/2.6	dusky purplish		
dark purplish blue	5.5PB	1.5/7.0	very dusky purple	5.5P	1.5/2.6
deep purplish blue	5.5PB	1.5/11.0	very dark purple	5.0P	1.5/7.0
			very deep purple	5.0P	1.5/11.0
PURPLES:			very pale reddish purple	9.5P	8.5/4.0
purplish white	6.0P	9.0/1.0	very light reddish purple	9.5P	8.5/7.0
light purplish white	6.0P	7.5/1.0	pale reddish purple	9.5P	6.5/4.0
medium purplish gray	0.5RP	5.5/1.0	light reddish purple	9.5P	6.5/7.0
dark purplish gray	0.5RP	3.5/1.0	brilliant reddish purple	9.5P	6.5/11.0
purplish black	0.5RP	1.5/1.0			
			weak reddish purple	9.5P	4.5/4.0
very pale bluish purple	10.0PB	8.0/4.0	moderate reddish purple	9.5P	4.5/7.0
very light bluish purple	10.0PB	7.7/7.0	strong reddish purple	9.5P	4.5/11.0
very brilliant bluish purple	10.0PB	7.5/11.0	vivid reddish purple	9.5P	4.5/14.0
pale bluish purple	10.0PB	5.5/4.0			
light bluish purple	10.0PB	5.5/7.0	dusky reddish purple	9.5P	3.0/4.0
brilliant bluish purple	10.0PB	5.5/11.0	dark reddish purple	9.5P	3.0/7.0
			deep reddish purple	9.5P	3.0/11.0
weak bluish purple	10.0PB	3.5/4.0			
moderate bluish purple	10.0PB	3.5/7.0	very dusky reddish purple	9.5P	1.5/4.0
strong bluish purple	10.0PB	3.5/11.0	very dark reddish purple	9.5P	1.5/7.0
vivid bluish purple	10.0PB	4.5/14	very deep reddish purple	9.5P	1.5/11.0
dusky bluish purple	10.0PB	1.5/4.0			
dark bluish purple	10.0PB	1.5/7.0	pale red purple	6.5RP	6.0/2.7
deep bluish purple	10.0PB	1.5/11.0	light red purple	4.5RP	6.0/8.0
			brilliant red purple	4.5RP	6.0/12.0
very pale purple	5.5P	8.5/2.6			
very light purple	5.0P	8.5/7.0	weak red purple	6.5RP	4.5/2.7
			moderate red purple	4.5RP	4.5/7.0
pale purple	5.5P	6.5/2.6	strong red purple	4.5RP	4.5/1000
light purple	5.0P	6.5/7.0	vivid red purple	4.5RP	4.0/14.0
brilliant purple	5.0P	6.5/11.0			
			dusky red purple	6.5RP	3.0/2.7
weak purple	5.5P	4.5/2.6	dark red purple	4.5RP	3.0/7.0
moderate purple	5.0P	4.5/7.0	deep red purple	4.5RP	3.0/11.0
strong purple	5.0P	4.5/11.0			
vivid purple	5.0P	4.5/14.0	very dusky red purple	6.5RP	1.5/2.7
			very dark red purple	4.5RP	1.5/7.0
dusky purple	5.5P	3.0/2.6	very deep red purple	4.5RP	1.5/11.0
dark purple	5.0P	3.0/7.0			
deep purple	5.0P	3.0/11.0			

Table A-15. Tristimulus Values of the Spectrum

WAVE-LENGTH (microns)	$\bar{x}$	$\bar{y}$	$\bar{z}$	WAVE-LENGTH (microns)	$\bar{x}$	$\bar{y}$	z
0.380	0.0014	0.0000	0.0065	0.580	0.9163	0.8700	0.0017
.385	0.0022	0.0001	0.0105	.585	0.9786	0.8163	0.0014
.390	0.0042	0.0001	0.0201	.590	1.0263	0.7570	0.0011
.395	0.0076	0.0002	0.0362	.595	1.0567	0.6949	0.0010
.400	0.0143	0.0004	0.0679	.600	1.0622	0.6310	0.0008
.405	0.0232	0.0006	0.1102	.605	1.0456	0.5668	0.0006
.410	0.0435	0.0012	0.2074	.610	1.0026	0.5030	0.0003
.415	0.0776	0.0022	0.3713	.615	0.9384	0.4412	0.0002
.420	0.1344	0.0040	0.6456	.620	0.8544	0.3810	0.0002
.425	0.2148	0.0073	1.0391	.625	0.7514	0.3210	0.0001
.430	0.2839	0.0116	1.3856	.630	0.6424	0.2650	0.0000
.435	0.3285	0.0168	1.6230	.635	0.5419	0.2170	0.0000
.440	0.3483	0.0230	1.7471	.640	0.4479	0.1750	0.0000
.445	0.3481	0.0298	1.7826	.645	0.3608	0.1382	0.0000
.450	1.3362	0.0380	1.7721	.650	0.2835	0.1070	0.0000
.455	0.3187	0.0480	1.7441	.655	0.2187	0.0816	0.0000
.460	0.2908	0.0600	1.6692	.660	0.1649	0.0610	0.0000
.465	0.2511	0.0739	1.5281	.665	0.1212	0.0446	0.0000
.470	0.1954	0.0910	1.2876	.670	0.0874	0.0320	0.0000
.475	0.1421	0.1126	1.0419	.675	0.0636	0.0232	0.0000
.480	0.0956	0.1390	0.8130	.680	0.0468	0.0170	0.0000
.485	0.0580	0.1693	0.6162	.685	0.0329	0.0119	0.0000
.490	0.0320	0.2080	0.4652	.690	0.0227	0.0082	0.0000
.495	0.0147	0.2586	0.3533	.695	0.0158	0.0057	
.500	0.0049	0.3230	0.2720	.700	0.0114	0.0041	0.0000
.505	0.0024	0.4073	0.2123	.705	0.0081	0.0029	0.0000
.510	0.0093	0.5030	0.1582	.710	0.0058	0.0021	0.0000
.515	0.0291	0.6082	0.1117	.715	0.0041	0.0015	0.0000
.520	0.0633	0.7100	0.0782	.720	0.0029	0.0010	0.0000
.525	0.1096	0.7932	0.0573	.725	0.0020	0.0007	0.0000
.530	0.1655	0.8620	0.0422	.730	0.0014	0.0005	0.0000
.535	0.2257	0.9149	0.0298	.735	0.0010	0.0004	0.0000
.540	0.2904	0.9540	0.0203	.740	0.0007	0.0003	0.0000
.545	0.3597	0.9803	0.0134	.745	0.0005	0.0002	0.0000
.550	0.4334	0.9950	0.0087	.750	0.0003	0.0001	0.0000
.555	0.5121	1.0002	0.0057	.755	0.0002	0.0001	0.0000
.560	0.5945	0.9950	0.0039	.760	0.0002	0.0001	0.0000
.565	0.6784	0.9786	0.0027	.765	0.0001	0.0000	0.0000
.570	0.7621	0.9520	0.0021	.770	0.0001	0.0000	0.0000
.575	0.8425	0.9154	0.0018	.775	0.0000	0.0000	0.0000
.580	0.9163	0.8700	0.0017	.780	0.0000	0.0000	0.0000
Totals					21.3713	21.3714	21.3715

Table A-16. Colors Associated with Various Material Temperatures

CENTRIGRADE	FAHRENHEIT	APPEARANCE
450	842	Visible in the dark
525	977	Visible in the daylight
575	1,067	Dark red
600	1,112	Dull red
830	1,526	Light red
875	1,607	Light cherry
900	1,652	Orange
940	1,724	Light orange
1,000	1,832	Yellow
1,080	1,976	Light yellow
1,180	2,156	White
1,300	2,372	Brilliant white

Table A-17. Conversion Factors for Lighting Units

ILLUMINATION

1 lumen = 1/650 lightwatt
1 lumen-hour = 60 lumen-minutes
1 footcandle = 1 lumen/sq ft
1 watt-second = 10^7 ergs
1 phot = 1 lumen/sq cm
1 lux = 1 lumen/sq M = 1 meter-candle

Number of → / Multiplied by ↘ / Equals Number of ↓	FOOTCANDLES	LUX	PHOT	MILLIPHOT
Footcandles	1	0.0929	929	0.929
Lux	10.76	1	10,000	10
Phot	0.00108	0.0001	1	0.001
Milliphot	1.076	0.1	1,000	1

BRIGHTNESS

1 stilb = 1 candle/sq cm
1 apostilb (international) = 0.1 millilambert = 1 blondel
1 apostilb (German Hefner) = 0.9 millilambert

Number of → / Multiplied by ↘ / Equals Number of ↓	FOOT-LAMBERT	LAMBERT	MILLI-LAMBERT	CANDLE/SQ IN.	CANDLE/SQ FT	STILB
Footlambert	1	929	0.929	452	3.142	2,919
Lambert	0.00108	1	0.001	0.487	0.0034	3.142
Millilambert	1.076	1,000	1	487	3.381	3,142
candle/sq in	0.00221	2.054	0.00205	1	0.00694	6.45
candle/sq ft	0.3183	295.7	0.2957	144	1	929
Stilb	0.00034	0.3183	0.00032	0.155	0.00108	1

INTENSITY

1 international candle = 1 bougie decimale = 1.11 Hefner Kerze

Table A-18. Approximate Brightness of Various Light Sources

LIGHT SOURCE		BRIGHTNESS (lamberts)
Natural light sources:		
Sun (as observed from earth's surface)	At meridian	519,000
Sun (as observed from earth's surface)	Near horizon	1,885
Moon (as observed from earth's surface)	Bright spot	0.8
Clear sky	Average brightness	2.5
Overcast sky		0.7 or less
Combustion sources:		
Candle flame (sperm)	Bright spot	3.1
Kerosene flame (flat wick)	Bright spot	3.8
Illuminating-gas flame	Fish-tail burner	1.3
Welsbach mantle	Bright spot	20
Acetylene flame	Mees burner	34
Blackbody 6500 K		922,000
4000 K		76,500
Incandescent electric lamps:		
Carbon filament	4 watts per candle	165
"Gem" filament	2.5 watts per candle	300
Nernst glower	2.3 watts per candle	810
Tantalum filament	2.0 watts per candle	225
Tungsten filament	Vacuum lamp, 10 lumens per watt	650
Tungsten filament	Gas-filled lamp, 20 lumens per watt	3,800
Tungsten filament	750-watt projector lamp, 26 lumens per watt	7,500
25-watt, inside-frosted lamp bulb		7–15
60-watt, inside-frosted lamp bulb		29
Fluorescent lamps:		
40-watt		
white T-12 tube		1.95
daylight T-12 tube		1.67
15-watt		
white T-12 tube		1.49
white T-8 tube		2.29
Electric arc lamps:		
Plain carbon arc	Crater	50,000
High-intensity carbon arc	13.6-mm rotating positive carbon	220,000
Super-high-intensity carbon arc	13.6-mm rotating positive carbon	280,000
Flaming arc		2,430
Magnetite arc		1,950
Low-pressure mercury arc	50-in. a-c rectifier tube	6.6
High-intensity mercury arc	Type H1, 1.4 atmospheres	440
High-pressure mercury arc	Type H4, 8 atmospheres	2,800
Water-cooled, high-pressure mercury arc	Type H6, 75 atmospheres	94,000
Water-cooled, high-pressure mercury arc	200 atmospheres	565,000
High-voltage neon tube	0.45-in. tube	0.6
High-voltage mercury tube	0.45-in. tube	0.18
Low-voltage, hot-cathode neon arc	18-in. a-c rectifier tube	14
Sodium arc lamp	10,000-lumen	18

Table A-19. Conversion Equations: Heat, Power, Work, Weights, and Measures

Atmosphere
76 centimeters of mercury at 0 C
29.92 inches of mercury at 0 C
406.8 inches of water at 4 C
14.7 pounds per square inch

British Thermal Unit
Amount of heat required to raise the temperature of one pound of water, 1 degree F
252 calories
778.3 foot-pounds
0.2928 watt-hour

Calorie
Amount of heat required to raise the temperature of one gram of water 1 degree C
0.003969 Btu
3.087 foot-pounds
0.001163 watt-hour

Circular Mil
Area of circle whose diameter is 1 mil or .001 inch
0.000000785 square inch
0.000005067 square centimeter

Degree (arc)
60 minutes
3600 seconds
0.01745 radian

Foot-Pound
0.001285 Btu
1.356 joules

Foot of Water
0.0295 atmosphere
62.43 pounds per square foot
0.4335 pound per square inch
2.242 centimeters of mercury

Gallon
0.1337 cubic foot
231 cubic inches
3.785 liters
8.336 pounds of water

Grain
0.06481 gram
0.002286 ounce

Gram
15.43 grains
0.03527 ounce
0.002205 pound

Gravity
32.1740 feet per second per second
980.665 centimeters per second per second

Horsepower
550 foot-pounds per second
33.000 foot-pounds per minute
42.41 Btu per minute
745.7 watts

Joule
1 watt-second
0.7376 foot-pound
0.000948O Btu

Kilogram
1000 grams
2.2046 pounds
35.274 ounces

Kilowatt
1.341 horsepower
44,257 foot-pounds per minute
56.89 Btu per minute

Liter
0.001 cubic meter
1.057 quarts
0.2642 gallon
0.03531 cubic feet

Miles per Hour
1 mph = 1.467 feet per second
1 mph = 88 feet per minute
1 mph = 44.7 centimeters per second

Ounce
0.0625 pound
28.35 grams
437.5 grains

Pound (Avoirdupois)
16 ounces
0.4536 kilogram
7000 grains
1.2153 pounds Troy

Quart
2 pints
0.25 gallon
0.9464 liter
2.084 pounds of water

Radian
57.296 degrees
57° 17′ 44.81″
360° ÷ 2π

Watt
44.26 foot-pounds per minute
0.001 kilowatt
0.00134 horsepower

Table A-20. Greek Alphabet (Capitals and Lower Case)

CAP.	L.C.	GR. NAME	CAP.	L.C.	GR. NAME
A	α	Alpha	N	ν	Nu
B	β	Beta	Ξ	ξ	Xi
Γ	γ	Gamma	O	o	Omicron
Δ	δ	Delta	Π	π	Pi
E	ϵ	Epsilon	P	ρ	Rho
Z	ζ	Zeta	Σ	σ, s	Sigma
H	η	Eta	T	τ	Tau
Θ	θ	Theta	Υ	υ	Upsilon
I	ι	Iota	Φ	ϕ	Phi
K	κ	Kappa	X	χ	Chi
Λ	λ	Lambda	Ψ	ψ	Psi
M	μ	Mu	Ω	ω	Omega

Table A-21. Values of Radians in Degrees

1 Radian = 57.29578 deg. 2 Radians = 114.59156 deg. 3 Radians = 171.88734 deg,

Radians	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
	deg.	*deg.*	*deg.*	*deg.*	*deg.*	*deg.*	*deg.*	*deg.*	*deg.*	*deg.*
0.0	0.0000	0.5730	1.1459	1.7189	2.2918	2.8648	3.4377	4.0107	4.5837	5.1566
0.1	5.7296	6.3025	6.8755	7.4485	8.0214	8.5944	9.1673	9.7403	10.3132	10.8862
0.2	11.4592	12.0321	12.6051	13.1780	13.7510	14.3239	14.8969	15.4699	16.0428	16.6158
0.3	17.1887	17.7617	18.3346	18.9076	19.4806	20.0535	20.6265	21.1994	21.7724	22.3454
0.4	22.9183	23.4913	24.0642	24.6372	25.2101	25.7831	26.3561	26.9290	27.5020	28.0749
0.5	28.6479	29.2208	29.7938	30.3668	30.9397	31.1527	32.0856	32.6586	33.2316	33.8045
0.6	34.3775	34.9504	35.5234	36.0963	36.6693	37.2423	37.8152	38.3882	38.9611	39.5341
0.7	40.1070	40.6800	41.2530	41.8259	42.3989	42.9718	43.5448	44.1178	44.6907	45.2637
0.8	45.8366	46.4096	46.9825	47.5555	48.1285	48.7014	49.2744	49.8473	50.4203	50.9932
0.9	51.5662	52.1392	52.7121	53.2851	53.8580	54.4310	55.0039	55.5769	56.1499	56.7228

Table A-22. Temperature Conversion

(F to C) $C = 5/9\ (F - 32)$ (C to F) $F = 9/5\ C + 32$

C	−15	−10	−5	0	5	10	15	20
F	5	14	23	32	41	50	59	68
C	25	30	35	40	45	50	55	60
F	77	86	95	104	113	122	131	140
C	65	70	75	80	85	90	95	100
F	149	158	167	176	185	194	203	212

Table A-23. Relations Between the Practical and Corresponding Cgs Electrical Units

QUANTITY	SYMBOL	PRACTICAL UNIT	CGS ELECTROMAGNETIC UNIT	CGS ELECTROSTATIC UNIT
Emf	E	volt	$= 10^8$ abvolts	$= 3.\dot{3} \times 10^{-2}$ statvolt*
Resistance	R	ohm	$= 10^9$ abohms	$= 1.1 \times 10^{-12}$ statohm
Current	I	ampere	$= 10^{-1}$ abampere	$= 3 \times 10^9$ statampere
Quantity	Q	coulomb	$= 10^{-1}$ abcoulomb	$= 3 \times 10^9$ statcoulomb
Capacitance	C	farad	$= 10^{-9}$ abfarad	$= 9 \times 10^{11}$ statfarad
Inductance	L	henry	$= 10^9$ abhenrys	$= 1.\dot{1} \times 10^{-12}$ stathenry*
Energy	W	joule	$= 10^7$ ergs	$= 10^7$ ergs
Power	P	watt	$= 10^7$ ergs/sec	$= 10^7$ ergs/sec

* Dot over number indicates a recurring decimal.

Table A-24. Natural or Naperian Logarithms of Numbers

N	0	2	4	6	8	N	0	2	4	6	8	N	0	2	4	6	3
1.0	**0.0000**	**0.0198**	**0.0392**	**0.0583**	**0.0770**	**4.0**	**1.3863**	**1.3913**	**1.3962**	**1.4012**	**1.4061**	**7.0**	**1.9459**	**1.9488**	**1.9516**	**1.9544**	**1.9573**
1.1	0.0953	0.1133	0.1310	0.1484	0.1655	4.1	1.4110	1.4159	1.4207	1.4255	1.4303	7.1	1.9601	1.9629	1.9657	1.9685	1.9713
1.2	0.1823	0.1989	0.2151	0.2311	0.2469	4.2	1.4351	1.4398	1.4446	1.4493	1.4540	7.2	1.9741	1.9769	1.9796	1.9824	1.9851
1.3	0.2624	0.2776	0.2927	0.3075	0.3221	4.3	1.4586	1.4633	1.4679	1.4725	1.4770	7.3	1.9879	1.9906	1.9933	1.9961	1.9988
1.4	0.3365	0.3507	0.3646	0.3784	0.3920	4.4	1.4816	1.4861	1.4907	1.4951	1.4996	7.4	2.0015	2.0042	2.0069	2.0096	2.0122
1.5	0.4055	0.4187	0.4318	0.4447	0.4574	4.5	1.5041	1.5085	1.5129	1.5173	1.5217	7.5	2.0149	2.0176	2.0202	2.0229	2.0255
1.6	0.4700	0.4824	0.4947	0.5068	0.5188	4.6	1.5261	1.5304	1.5347	1.5390	1.5433	7.6	2.0281	2.0308	2.0334	2.0360	2.0386
1.7	0.5306	0.5423	0.5539	0.5653	0.5766	4.7	1.5476	1.5518	1.5560	1.5602	1.5644	7.7	2.0412	2.0438	2.0464	2.0490	2.0516
1.8	0.5878	0.5988	0.6098	0.6206	0.6313	4.8	1.5686	1.5728	1.5769	1.5810	1.5851	7.8	2.0541	2.0567	2.0592	2.0618	2.0643
1.9	0.6419	0.6523	0.6627	0.6729	0.6831	4.9	1.5892	1.5933	1.5974	1.6014	1.6054	7.9	2.0669	2.0694	2.0719	2.0744	2.0769
2.0	**0.6931**	**0.7031**	**0.7129**	**0.7227**	**0.7324**	**5.0**	**1.6094**	**1.6134**	**1.6174**	**1.6214**	**1.6253**	**8.0**	**2.0794**	**2.0819**	**2.0844**	**2.0869**	**2.0894**
2.1	0.7419	0.7514	0.7608	0.7701	0.7793	5.1	1.6292	1.6332	1.6371	1.6409	1.6448	8.1	2.0919	2.0943	2.0968	2.0992	2.1017
2.2	0.7885	0.7975	0.8065	0.8154	0.8242	5.2	1.6487	1.6525	1.6563	1.6601	1.6639	8.2	2.1041	2.1066	2.1090	2.1114	2.1138
2.3	0.8329	0.8416	0.8502	0.8587	0.8671	5.3	1.6677	1.6715	1.6752	1.6790	1.6827	8.3	2.1163	2.1187	2.1211	2.1235	2.1258
2.4	0.8755	0.8838	0.8920	0.9002	0.9083	5.4	1.6864	1.6901	1.6938	1.6974	1.7011	8.4	2.1282	2.1306	2.1330	2.1353	2.1377
2.5	0.9163	0.9243	0.9322	0.9400	0.9478	5.5	1.7047	1.7084	1.7120	1.7156	1.7192	8.5	2.1401	2.1424	2.1448	2.1471	2.1494
2.6	0.9555	0.9632	0.9708	0.9783	0.9858	5.6	1.7228	1.7263	1.7299	1.7334	1.7370	8.6	2.1518	2.1541	2.1564	2.1587	2.1610
2.7	0.9933	1.0006	1.0080	1.0152	1.0225	5.7	1.7405	1.7440	1.7475	1.7509	1.7544	8.7	2.1633	2.1656	2.1679	2.1702	2.1725
2.8	1.0296	1.0367	1.0438	1.0508	1.0578	5.8	1.7579	1.7613	1.7647	1.7681	1.7716	8.8	2.1748	2.1770	2.1793	2.1815	2.1838
2.9	1.0647	1.0716	1.0784	1.0852	1.0919	5.9	1.7750	1.7783	1.7817	1.7851	1.7884	8.9	2.1861	2.1883	2.1905	2.1928	2.1950
3.0	**1.0986**	**1.1053**	**1.1119**	**1.1184**	**1.1249**	**6.0**	**1.7918**	**1.7951**	**1.7984**	**1.8017**	**1.8050**	**9.0**	**2.1972**	**2.1994**	**2.2017**	**2.2039**	**2.2061**
3.1	1.1314	1.1378	1.1442	1.1506	1.1569	6.1	1.8083	1.8116	1.8148	1.8181	1.8213	9.1	2.2083	2.2105	2.2127	2.2148	2.2170
3.2	1.1632	1.1694	1.1756	1.1817	1.1878	6.2	1.8245	1.8278	1.8310	1.8342	1.8374	9.2	2.2192	2.2214	2.2235	2.2257	2.2279
3.3	1.1939	1.2000	1.2060	1.2119	1.2179	6.3	1.8405	1.8437	1.8469	1.8500	1.8532	9.3	2.2300	2.2322	2.2343	2.2364	2.2386
3.4	1.2238	1.2296	1.2355	1.2413	1.2470	6.4	1.8563	1.8594	1.8625	1.8656	1.8687	9.4	2.2407	2.2428	2.2450	2.2471	2.2492
3.5	1.2528	1.2585	1.2641	1.2698	1.2754	6.5	1.8718	1.8749	1.8779	1.8810	1.8840	9.5	2.2513	2.2534	2.2555	2.2576	2.2597
3.6	1.2809	1.2865	1.2920	1.2975	1.3029	6.6	1.8871	1.8901	1.8931	1.8961	1.8991	9.6	2.2618	2.2638	2.2659	2.2680	2.2701
3.7	1.3083	1.3137	1.3191	1.3244	1.3297	6.7	1.9021	1.9051	1.9081	1.9110	1.9140	9.7	2.2721	2.2742	2.2762	2.2783	2.2803
3.8	1.3350	1.3403	1.3455	1.3507	1.3558	6.8	1.9169	1.9199	1.9228	1.9257	1.9286	9.8	2.2824	2.2844	2.2865	2.2885	2.2905
3.9	1.3610	1.3661	1.3712	1.3762	1.3813	6.9	1.9315	1.9344	1.9373	1.9402	1.9430	9.9	2.2925	2.2946	2.2966	2.2986	2.3006

The natural logarithm of a number is the index of the power to which the base e (2.7182818) must be raised in order to equal the number.

To find the natural logarithm of a number larger than 10 or smaller than 1, add or subtract the natural logarithm of the proper power of 10. For example:

The natural logarithm of 123

$$\log_e 123 = \log_e 1.23 + \log_e 10^2 = 0.2070 - 4.6052 = 4.8122$$

$$\log_e 0.123 = \log_e 1.23 - \log_e 10 = 0.2070 - 2.3026 = -2.0956$$

$$\log_e 10 = 2.302\ 585 \qquad \log_e 10^4 = 9.210\ 340$$
$$\log_e 10^2 = 4.605\ 170 \qquad \log_e 10^5 = 11.512\ 925$$
$$\log_e 10^3 = 6.907\ 755 \qquad \log_e 10^6 = 13.815\ 511$$

To obtain the common logarithm, multiply the natural logarithm by $\log_{10} e$, which is 0.434 294.

Table A-25. Natural Trigonometric Functions

α	$\cos^2 \alpha$	$\cos^3 \alpha$	α	$\cos^2 \alpha$	$\cos^3 \alpha$
0	1.00	1.000	46	.482	.335
1	.999	.999	47	.465	.317
2	.998	.998	48	.447	.299
3	.997	.996	49	.430	.282
4	.995	.993	50	.413	.265
5	.992	.988	51	.395	.249
6	.989	.983	52	.379	.233
7	.985	.978	53	.362	.218
8	.981	.971	54	.345	.203
9	.975	.963	55	.329	.189
10	.970	.955	56	.312	.175
11	.963	.946	57	.296	.161
12	.957	.936	58	.280	.149
13	.949	.925	59	.265	.137
14	.941	.913	60	.250	.125
15	.933	.901	61	.235	.113
16	.924	.888	62	.220	.103
17	.914	.874	63	.206	.0936
18	.904	.860	64	.192	.0843
19	.894	.845	65	.178	.0755
20	.883	.830	66	.165	.0673
21	.872	.814	67	.152	.0596
22	.859	.797	68	.140	.0526
23	.847	.780	69	.128	.0460
24	.834	.762	70	.117	.0400
25	.821	.744	71	.106	.0345
26	.808	.725	72	.0955	.0295
27	.794	.707	73	.0855	.0250
28	.779	.688	74	.0759	.0209
29	.764	.669	75	.0670	.0173
30	.750	.649	76	.0586	.0142
31	.735	.630	77	.0506	.0114
32	.719	.610	78	.0432	.00899
33	.703	.590	79	.0363	.00686
34	.687	.570	80	.0301	.00520
35	.671	.550	81	.0244	.00379
36	.655	.529	82	.0193	.00268
37	.637	.509	83	.0148	.00181
38	.621	.489	84	.0109	.00115
39	.604	.469	85	.00760	.000661
40	.587	.449	86	.00486	.000339
41	.569	.430	87	.00274	.000144
42	.552	.410	88	.00122	.0000425
43	.534	.391	89	.000306	.0000053
44	.517	.372	90	.0000	.0000
45	.500	.353			
	$\sin^2 \alpha$	$\sin^3 \alpha$		$\sin^2 \alpha$	$\sin^3 \alpha$

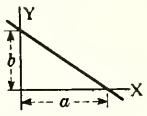
Table A-25—Continued

Degrees	Sines		Degrees	Cosines		Degrees	Tangents		Degrees	Cotangents	
0	0.00000	90	0	1.00000	90	0	0.00000	90	0	∞	90
1	0.01745	89	1	0.99985	89	1	0.01746	89	1	57.28996	89
2	0.03490	88	2	0.99939	88	2	0.03492	88	2	28.63625	88
3	0.05234	87	3	0.99863	87	3	0.05241	87	3	19.08114	87
4	0.06976	86	4	0.99756	86	4	0.06993	86	4	14.30067	86
5	0.08716	85	5	0.99619	85	5	0.08749	85	5	11.43005	85
6	0.10453	84	6	0.99452	84	6	0.10510	84	6	9.51436	84
7	0.12187	83	7	0.99255	83	7	0.12278	83	7	8.14435	83
8	0.13917	82	8	0.99027	82	8	0.14054	82	8	7.11537	82
9	0.15643	81	9	0.98769	81	9	0.15838	81	9	6.31375	81
10	0.17365	80	10	0.98481	80	10	0.17633	80	10	5.67128	80
11	0.19081	79	11	9.98163	79	11	0.19438	79	11	5.14455	79
12	0.20791	78	12	0.97815	78	12	0.21256	78	12	4.70463	78
13	0.22495	77	13	0.97437	77	13	0.23087	77	13	4.33148	77
14	0.24192	76	14	0.97030	76	14	0.24933	76	14	4.01078	76
15	0.25882	75	15	0.96593	75	15	0.26795	75	15	3.73205	75
16	0.27564	74	16	0.96126	74	16	0.28675	74	16	3.48741	74
17	0.29237	73	17	0.95630	73	17	0.30573	73	17	3 27085	73
18	0.30902	72	18	0.95106	72	18	0.32492	72	18	3.07768	72
19	0.32557	71	19	0.94552	71	19	0.34433	71	19	2.90421	71
20	0.34202	70	20	0.93969	70	20	0.36397	70	20	2.74748	70
21	0.35837	69	21	0.93358	69	21	0.38386	69	21	2.60509	69
22	0.37461	68	22	0.92718	68	22	0.40403	68	22	2.47509	68
23	0.39073	67	23	0.92050	67	23	0.42447	67	23	2.35585	67
24	0.40674	66	24	0.91355	66	24	0.44523	66	24	2.24604	66
25	0.42262	65	25	0.90631	65	25	0.46631	65	25	2.14451	65
26	0.43837	64	26	0.89879	64	26	0.48773	64	26	2.05030	64
27	0.45399	63	27	0.89101	63	27	0.50953	63	27	1.96261	63
28	0.46947	62	28	0.88295	62	28	0.53171	62	28	1.88073	62
29	0.48481	61	29	0.87462	61	29	0.55431	61	29	1.80405	61
30	0.50000	60	30	0.86603	60	30	0.57735	60	30	1.73205	60
31	0.51504	59	31	0.85717	59	31	0.60086	59	31	1.66428	59
32	0.52992	58	32	0.84805	58	32	0.62487	58	32	1.60033	58
33	0.54464	57	33	0.83867	57	33	0.64941	57	33	1.53987	57
34	0.55919	56	34	0.82904	56	34	0.67451	56	34	1.48256	56
35	0.57358	55	35	0.81915	55	35	0.70021	55	35	1.42815	55
36	0.58779	54	36	0.80902	54	36	0.72654	54	36	1.37638	54
37	0.60182	53	37	0.79864	53	37	0.75355	53	37	1.32704	53
38	0.61566	52	38	0.78801	52	38	0.78129	52	38	1.27994	52
39	0.62932	51	39	0.77715	51	39	0.80978	51	39	1.23490	51
40	0.64279	50	40	0.76604	50	40	0.83910	50	40	1.19175	50
41	0.65606	49	41	0.75471	49	41	0.86929	49	41	1.15037	49
42	0.66913	48	42	0.74314	48	42	0.90040	48	42	1.11061	48
43	0.68200	47	43	0.73135	47	43	0.93252	47	43	1.07237	47
44	0.69466	46	44	0.71934	46	44	0.96569	46	44	1.03553	46
45	0.70711	45	45	0.70711	45	45	1.00000	45	45	1.00000	45
	Cosines	Degrees		Sines	Degrees		Cotangents	Degrees		Tangents	Degrees

Table A-26. Equations of Common Curves

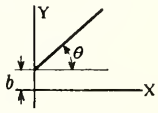
(Straight line)

$$\frac{x}{a} + \frac{y}{b} = 1$$



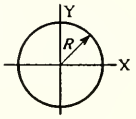
or

$$y = x \tan \theta + b.$$



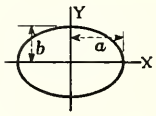
Circle.

$$x^2 + y^2 = R^2$$



Ellipse.

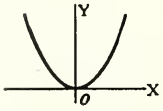
$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1.$$



Parabola (Vertical).

$$y = kx^2$$

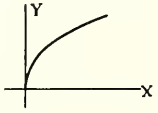
where k is a constant.



Parabola (Horizontal).

$$y = k\sqrt{x}$$

where k is a constant.



Catenary.

$$y = \frac{1}{k} \cosh kx - 1$$

where k is a constant. The length of arc from O to P

$$= \frac{1}{k} \sinh (kx)$$

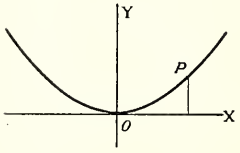


Table A-27. Areas of Plane Figures

Nomenclature

a, b, c, d	—Lengths of sides	l, l_1, l_2	—Length of arc
A	—Area	L	—Lateral length or slant height
d, d_1, d_2	—Diameters	n	—Number of sides
e, f	—Lengths of diagonals	θ	—Number of degrees of arc
h	—Vertical height or altitude	p	—Perimeter
		r, r_1, r_2, R	—Radii

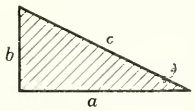
Right Triangle

$p = a + b + c$

$c^2 = a^2 + b^2$

$b = \sqrt{c^2 - a^2}$

$A = \frac{ab}{2}$

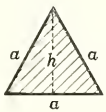


Equilateral Triangle

$p = 3a$

$h = \frac{a}{2}\sqrt{3} = .866\ a$

$A = a^2\frac{\sqrt{3}}{4} = .433\ a^2$



General Triangle

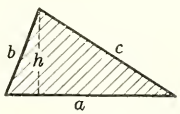
Let $s = \frac{a + b + c}{2}$

$p = a + b + c$

$h = \frac{2}{a}\sqrt{s(s - a)(s - b)(s - c)}$

$A = \frac{ah}{2}$

$A = \sqrt{s(s - a)(s - b)(s - c)}$



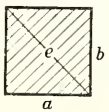
Square

$a = b$

$p = 4a$

$A = a^2 = .5e^2$

$e = a\sqrt{2} = 1.414\ a$



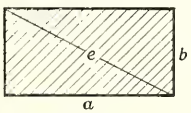
Rectangle

$p = 2(a + b)$

$e = \sqrt{a^2 + b^2}$

$b = \sqrt{e^2 - a^2}$

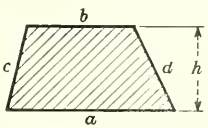
$A = ab$



Trapezoid

$p = a + b + c + d$

$A = \frac{(a + b)}{2}h$



Circle

$p = 2\pi r = \pi d = 3.1416d$

$A = \pi r^2 = \frac{\pi d^2}{4} = .7854d^2$

$= \frac{p^2}{4\pi} = .0795Sp^2$



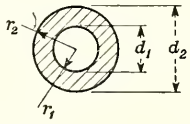
Hollow circle or Annulus

$A = \frac{\pi}{4}(d_2^2 - d_1^2) = .7854(d_2^2 - d_1^2)$

$= \pi(r_2^2 - r_1^2)$

$= \pi \frac{d_1 + d_2}{2}(r_2 - r_1)$

$= \pi(r_1 + r_2)(r_2 - r_1)$

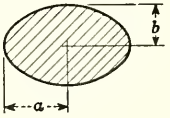


Ellipse

$p = \pi(a + b)$ approximately

$= \pi[1.5(a + b) - \sqrt{ab}]$ more nearly

$A = \pi ab$



Parabola

$A = \frac{2}{3}ab$

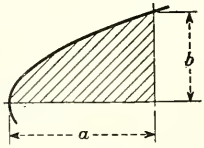
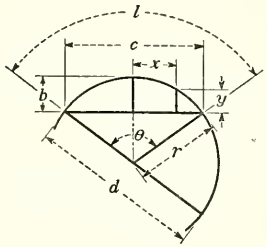


Table A-28. Properties of the Circle

Circumference of circle of diameter 1 = π = 3.14159265
Circumference of circle = $2\pi r = \pi d$
Diameter of circle = circumference × 0.31831
Diameter of circle of equal periphery as square = side × 1.27324
Side of square of equal periphery as circle = diameter × 0.78540
Diameter of circle circumscribed about square = side × 1.41421
Side of square inscribed in circle = diameter × 0.70711



Arc, $l = \frac{\pi r\theta^\circ}{180} = 0.017453\, r\, \theta^\circ$

Angle, $\theta = \frac{180^\circ\, l}{\pi r} = 57.29578\frac{l}{r}$

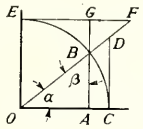
Radius, $r = \frac{4b^2 + c^2}{8b}$ Diameter, $d = \frac{4b^2 + c^2}{4b}$

Chord, $c = 2\sqrt{2br - b^2} = 2r\sin\frac{\theta}{2} = d\sin\frac{\theta}{2}$

Rise, $b = r - \frac{1}{2}\sqrt{4r^2 - c^2} = \frac{c}{2}\tan\frac{\theta}{4} = 2r\sin^2\frac{\theta}{4}$

Rise, $b = r + y - \sqrt{r^2 - x^2}$ $y = b - r + \sqrt{r^2 - x^2}$ $x = \sqrt{r^2 - (r + y - b)^2}$

Table A-29. Trigonometric Formulas



OC = OB = OE = 1
AB = Sin α
OA = Cos α
CD = Tan α
EF = Cot α
OD = Sec α
OF = Cosec α
AC = Vers α = 1 − Cos α
BG = Covers α = 1 − Sin α

Radius 1 $= \sin^2\alpha + \cos^2\alpha = \sin\alpha \operatorname{cosec}\alpha = \cos\alpha \sec\alpha = \tan\alpha \cot\alpha$

$$\sin\alpha = \frac{\cos\alpha}{\cot\alpha} = \frac{1}{\operatorname{cosec}\alpha} = \cos\alpha\tan\alpha = \sqrt{1-\cos^2\alpha}$$

$$\cos\alpha = \frac{\sin\alpha}{\tan\alpha} = \frac{1}{\sec\alpha} = \sin\alpha\cot\alpha = \sqrt{1-\sin^2\alpha}$$

$$\tan\alpha = \frac{\sin\alpha}{\cos\alpha} = \frac{1}{\cot\alpha} = \sin\alpha\sec\alpha \qquad \sec\alpha = \frac{\tan\alpha}{\sin\alpha} = \frac{1}{\cos\alpha}$$

$$\cot\alpha = \frac{\cos\alpha}{\sin\alpha} = \frac{1}{\tan\alpha} = \cos\alpha\operatorname{cosec}\alpha \qquad \operatorname{cosec}\alpha = \frac{\cot\alpha}{\cos\alpha} = \frac{1}{\sin\alpha}$$

$$\sin(\alpha \pm \beta) = \sin\alpha\cos\beta \pm \cos\alpha\sin\beta \qquad \tan(\alpha \pm \beta) = \frac{\tan\alpha \pm \tan\beta}{1 \mp \tan\alpha\tan\beta}$$

$$\cos(\alpha \pm \beta) = \cos\alpha\cos\beta \mp \sin\alpha\sin\beta \qquad \cot(\alpha \pm \beta) = \frac{\cot\alpha\cot\beta \mp 1}{\cot\beta \pm \cot\alpha}$$

$$\sin\alpha + \sin\beta = 2\sin\tfrac{1}{2}(\alpha+\beta)\cos\tfrac{1}{2}(\alpha-\beta) \qquad \tan\alpha + \tan\beta = \frac{\sin(\alpha+\beta)}{\cos\alpha\cos\beta}$$

$$\sin 2\alpha = 2\sin\alpha\cos\alpha \qquad \sin\tfrac{1}{2}\alpha = \sqrt{\frac{1-\cos\alpha}{2}} \qquad \sin^2\alpha = \frac{1-\cos 2\alpha}{2}$$

$$\cos 2\alpha = \cos^2\alpha - \sin^2\alpha \qquad \cos\tfrac{1}{2}\alpha = \sqrt{\frac{1+\cos\alpha}{2}} \qquad \cos^2\alpha = \frac{1+\cos 2\alpha}{2}$$

$$\tan 2\alpha = \frac{2\tan\alpha}{1-\tan^2\alpha} \qquad \tan\tfrac{1}{2}\alpha = \frac{\sin\alpha}{1+\cos\alpha} \qquad \tan^2\alpha = \frac{1-\cos 2\alpha}{1+\cos 2\alpha}$$

$$\cot 2\alpha = \frac{\cot^2\alpha - 1}{2\cot\alpha} \qquad \cot\tfrac{1}{2}\alpha = \frac{\sin\alpha}{1-\cos\alpha} \qquad \cot^2\alpha = \frac{1+\cos 2\alpha}{1-\cos 2\alpha}$$

$$\sin^2\alpha - \sin^2\beta = \sin(\alpha+\beta)\sin(\alpha-\beta) \qquad \cos^2\alpha - \sin^2\beta = \cos(\alpha+\beta)\cos(\alpha-\beta)$$

$$\frac{\sin\alpha \pm \sin\beta}{\cos\alpha + \cos\beta} = \tan\tfrac{1}{2}(\alpha \pm \beta) \qquad \frac{\sin\alpha \pm \sin\beta}{\cos\beta - \cos\alpha} = \cot\tfrac{1}{2}(\alpha \mp \beta)$$

Table A-30. Constants for Use in the Zonal Method of Computing Luminous Flux from Candlepower Data. (1, 2, 5, and 10 Degree Zones)

(Multiply average candlepower at center of zone by zonal constant to obtain lumens in zone)

1 DEGREE ZONES		2 DEGREE ZONES		5 DEGREE ZONES		10 DEGREE ZONES	
ZONE LIMITS (degrees)	ZONAL CONSTANT	ZONE LIMITS (degrees)	ZONAL CONSTANT	ZONE LIMITS (degrees)	ZONAL CONSTANT	ZONE LIMITS (degrees)	ZONAL CONSTANT
0– 1	0.0009	0– 2	0.0038	0– 5	0.0239	0–10	0.095
1– 2	.0029	2– 4	.0113	5–10	.0715	10–20	.284
2– 3	.0050	4– 6	.0195	10–15	.1186	20–30	.463
3– 4	.0063	6– 8	.0264	15–20	.1648	30–40	.628
4– 5	.0088	8–10	.0345	20–25	.2098	40–50	.774
5– 6	.0107	10–12	.0421	25–30	.2531	50–60	.897
6– 7	.0125	12–14	.0490	30–35	.2945	60–70	.993
7– 8	.0138	14–16	.0565	35–40	.3337	70–80	1.058
8– 9	.0163	16–18	.0640	40–45	.3703	80–90	1.091
9–10	.0182	18–20	.0720	45–50	.4041		
				50–55	.4349		
				55–60	.4623		
				60–65	.4862		
				65–70	.5064		
				70–75	.5228		
				75–80	.5352		
				80–85	.5435		
				85–90	.5476		

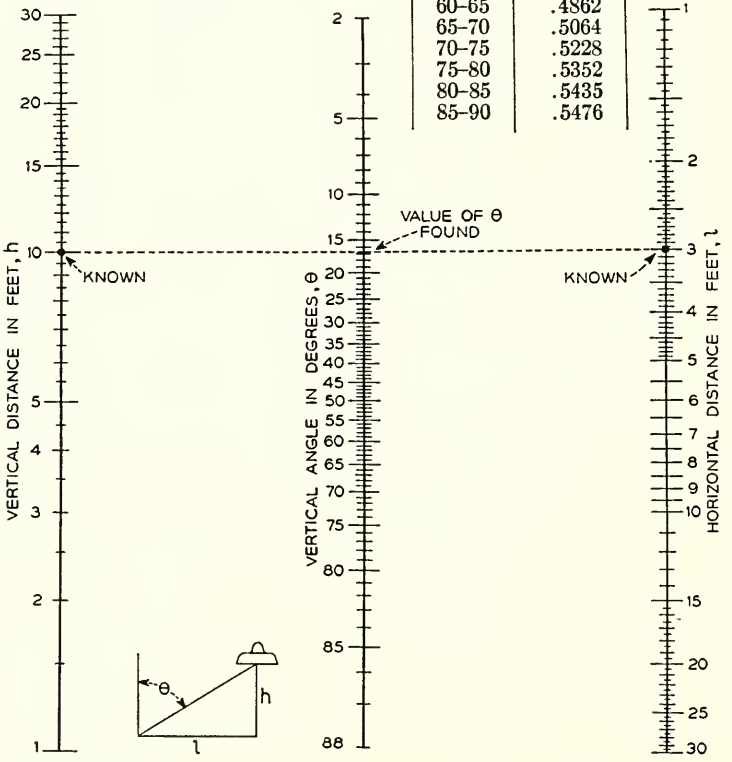


FIG. A-2. Nomogram for determining angle of incidence (θ) when height (h) above reference plane and horizontal distance (l) from point of incidence are known.

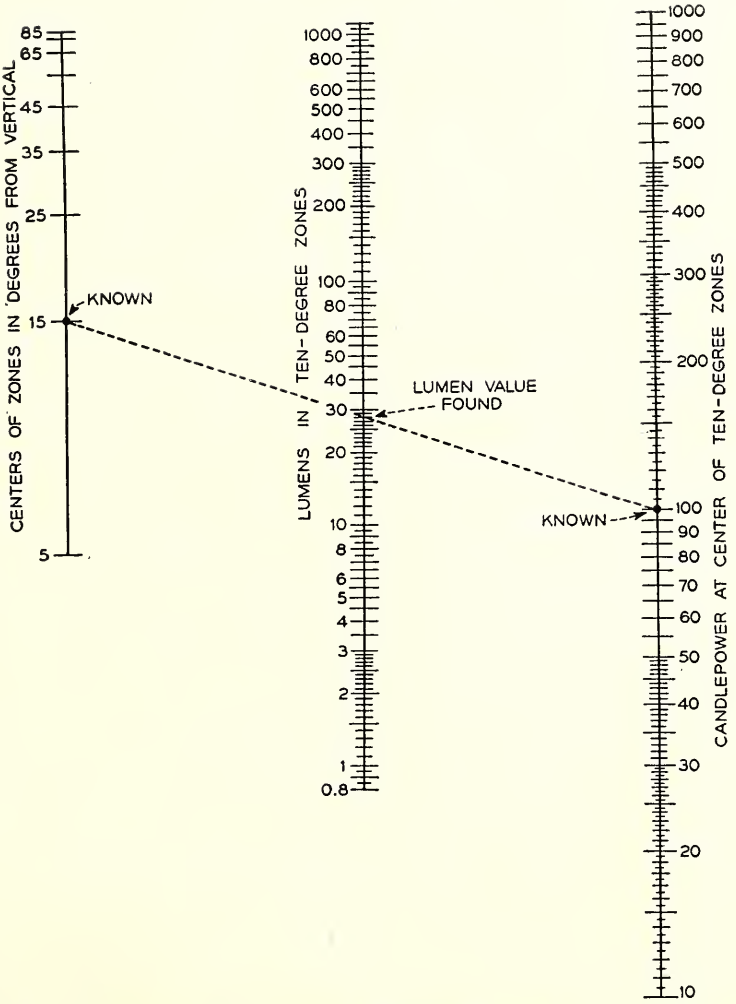


FIG. A-3. Nomogram for obtaining zonal lumens when average candlepower at center of ten degree zones is known.

Table A-31. Constants for Converting Beam Candlepower of Projector-Type Luminaires (Searchlights, Floodlights, Spotlights) into Lumens

(0.1 x 0.1 to 10 x 10 degree steps)

SPACING 0.1° VERTICAL

0.1° HORIZONTAL

HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K
0.05	0.53046	2.75	0.53043	5.45	0.53032
0.15	3046	2.85	3042	5.55	3032
0.25	3046	2.95	3042	5.65	3031
0.35	3046	3.05	3042	5.75	3031
0.45	3046	3.15	3042	5.85	3030
0.55	3046	3.25	3041	5.95	3030
0.65	3046	3.35	3041	6.05	3029
0.75	3046	3.45	3041	6.15	3029
0.85	3046	3.55	3040	6.25	3028
0.95	3046	3.65	3040	6.35	3028
1.05	3046	3.75	3040	6.45	3027
1.15	3046	3.85	3039	6.55	3026
1.25	3045	3.95	3039	6.65	3026
1.35	3045	4.05	3039	6.75	3025
1.45	3045	4.15	3038	6.85	3024
1.55	3045	4.25	3038	6.95	3024
1.65	3045	4.35	3037	7.05	3023
1.75	3045	4.45	3037	7.15	3023
1.85	3045	4.55	3037	7.25	3022
1.95	3044	4.65	3036	7.35	3021
2.05	3044	4.75	3036	7.45	3021
2.15	3044	4.85	3035	7.55	3020
2.25	3044	4.95	3035	7.65	3019
2.35	3044	5.05	3034	7.75	3018
2.45	3043	5.15	3034	7.85	3018
2.55	3043	5.25	3033	7.95	3017
2.65	3043	5.35	3033		

0.2° HORIZONTAL

HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K
0.1	0.56092	2.9	0.56085	5.5	0.56065
0.3	6092	3.1	6084	5.7	6063
0.5	6092	3.3	6083	5.9	6061
0.7	6092	3.5	6081	6.1	6058
0.9	6091	3.7	6080	6.3	6056
1.1	6091	5.9	6079	6.5	6054
1.3	6091	4.1	6077	6.7	6051
1.5	6090	4.3	6076	6.9	6049
1.7	6089	4.5	6074	7.1	6046
1.9	6089	4.7	6073	7.3	6044
2.1	6088	4.9	6071	7.5	6041
2.3	6087	5.1	6069	7.7	6038
2.5	6087	5.3	6067	7.9	6035
2.7	6086				

0.4° HORIZONTAL

HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K
0.2	0.41219	3.0	0.41217	5.8	0.41212
0.6	1218	3.4	1216	6.2	1211
1.0	1218	3.8	1216	6.6	1210
1.4	1218	4.2	1215	7.0	1210
1.8	1218	4.6	1215	7.4	1208
2.2	1217	5.0	1214	7.8	1207
2.6	1217	5.4	1213		

0.6° HORIZONTAL

HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K
0.3	0.41827	3.3	0.41825	5.7	0.41819
0.9	1827	3.9	1824	6.3	1816
1.5	1827	4.5	1822	6.9	1814
2.1	1827	5.1	1821	7.5	1810
2.7	1826				

0.8° HORIZONTAL

HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K
0.4	0.42437	3.6	0.42432	6.0	0.42424
1.2	2436	4.4	2429	6.8	2420
2.0	2435	5.2	2427	7.6	2416
2.8	2434				

1.0° HORIZONTAL

HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K
0.5	0.43046	3.5	0.43041	6.5	0.43027
1.5	3045	4.5	3037	7.5	3020
2.5	3043	5.5	3032		

SPACING 0.2° VERTICAL

0.2° HORIZONTAL

HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K
0.1	0.41219	2.9	0.41217	5.5	0.41213
0.3	1219	3.1	1217	5.7	1212
0.5	1218	3.3	1217	5.9	1212
0.7	1218	3.5	1216	6.1	1212
0.9	1218	3.7	1216	6.3	1211
1.1	1218	3.9	1216	6.5	1211
1.3	1218	4.1	1215	6.7	1210
1.5	1218	4.3	1215	6.9	1210
1.7	1218	4.5	1215	7.1	1209
1.9	1218	4.7	1214	7.3	1209
2.1	1218	4.9	1214	7.5	1208
2.3	1218	5.1	1214	7.7	1208
2.5	1217	5.3	1213	7.9	1207
2.7	1217				

0.4° HORIZONTAL

HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K
0.2	0.42437	3.0	0.42434	5.8	0.42425
0.6	2437	3.4	2433	6.2	2423
1.0	2437	3.8	2432	6.6	2421
1.4	2436	4.2	2430	7.0	2419
1.8	2436	4.6	2429	7.4	2417
2.2	2435	5.0	2428	7.8	2414
2.6	2434	5.4	2426		

0.6° HORIZONTAL

HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K
0.3	0.43655	3.3	0.43649	5.7	0.43637
0.9	3655	3.9	3647	6.3	3633
1.5	3654	4.5	3644	6.9	3629
2.1	3653	5.1	3641	7.5	3624
2.7	3651				

HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K
SPACING 0.2° VERTICAL											
0.8° HORIZONTAL						**1.0° HORIZONTAL**					
0.4	0.44874	3.6	0.44864	6.0	0.44848	0.5	0.46092	3.5	0.46082	6.5	0.46054
1.2	4872	4.4	4858	6.8	4840	1.5	6090	4.5	6074	7.5	6040
2.0	4870	5.2	4854	7.6	4832	2.5	6086	5.5	6064		
2.8	4868										
SPACING 0.4° VERTICAL											
0.2° HORIZONTAL						2.2	4870	5.0	4855	7.8	4829
0.1	0.42437	2.9	0.42434	5.5	0.42426	2.6	4869	5.4	4852		
0.3	2437	3.1	2434	5.7	2425						
0.5	2437	3.3	2433	5.9	2424	**0.6° HORIZONTAL**					
0.7	2437	3.5	2432	6.1	2423						
0.9	2437	3.7	2432	6.3	2422	0.3	0.47310	3.3	0.47299	5.7	0.47274
1.1	2437	3.9	2431	6.5	2421	0.6	7310	3.9	7294	6.3	7267
1.3	2436	4.1	2431	6.7	2420	1.5	7308	4.5	7288	6.9	7258
1.5	2436	4.3	2430	6.9	2419	2.1	7306	5.1	7282	7.5	7248
1.7	2436	4.5	2430	7.1	2418	2.7	7302				
1.9	2436	4.7	2429	7.3	2417						
2.1	2435	4.9	2428	7.5	2416	**0.8° HORIZONTAL**					
2.3	2435	5.1	2427	7.7	2415						
2.5	2434	5.3	2426	7.9	2414	0.4	0.49747	3.6	0.49728	6.0	0.49694
2.7	2434					1.2	9746	4.4	9719	6.8	9679
						2.0	9742	5.2	9707	7.6	9662
0.4° HORIZONTAL						2.8	9736				
0.2	0.44874	3.0	0.44867	5.8	0.34849	**1.0° HORIZONTAL**					
0.6	4874	3.4	4865	6.2	4846						
1.0	4874	3.8	4863	6.6	4842	0.5	0.31218	3.5	0.31216	6.5	0.31211
1.4	4872	4.2	4861	7.0	4838	1.5	1218	4.5	1215	7.5	1208
1.8	4872	4.6	4858	7.4	4834	2.5	1217	5.5	1212		
SPACING 0.6° VERTICAL											
0.2° HORIZONTAL						2.2	7306	5.0	7283	7.8	7243
0.1	0.43655	2.9	0.43650	5.5	0.43638	2.6	7303	5.4	7278		
0.3	3655	3.1	3650	5.7	3637						
0.5	3655	3.3	3649	5.9	3636	**0.6° HORIZONTAL**					
0.7	3655	3.5	3649	6.1	3635						
0.9	3655	3.7	3648	6.3	3634	0.3	0.31097	3.3	0.31095	5.7	0.31091
1.1	3655	3.9	3647	6.5	3632	0.9	1097	3.9	1094	6.3	1090
1.3	3654	4.1	3646	6.7	3631	1.5	1096	4.5	1093	6.9	1089
1.5	3654	4.3	3645	6.9	3629	2.1	1096	5.1	1092	7.5	1087
1.7	3654	4.5	3644	7.1	3628	2.7	1095				
1.9	3653	4.7	3643	7.3	3626						
2.1	5653	4.9	3642	7.5	3625	**0.8° HORIZONTAL**					
2.3	3653	5.1	3641	7.7	3622						
2.5	3652	5.3	3640	7.9	3621	0.4	0.31462	3.6	0.31459	6.0	0.31454
2.7	3652					1.2	1462	4.4	1458	6.8	1452
						2.0	1461	5.2	1456	7.6	1449
0.4° HORIZONTAL						2.8	1460				
0.2	0.47310	3.0	0.47301	5.8	0.47273	**1.0° HORIZONTAL**					
0.6	7310	3.4	7299	6.2	7268						
1.0	7310	3.8	7295	6.6	7262	0.5	0.31828	3.5	0.31824	6.5	0.31816
1.4	7308	4.2	7292	7.0	7256	1.5	1827	4.5	1822	7.5	1812
1.8	7307	4.6	7288	7.4	7250	2.5	1826	5.5	1819		

SPACING 0.8° VERTICAL

0.2° HORIZONTAL

HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K
0.1	0.44874	2.9	0.44867	5.5	0.44851
0.3	4874	3.1	4867	4.7	4850
0.5	4874	3.3	4866	5.9	4848
0.7	4874	3.5	4865	6.1	4846
0.9	4874	3.7	4864	6.3	4845
1.1	4874	3.9	4862	6.5	4842
1.3	4872	4.1	4862	6.7	4841
1.5	4872	4.3	4860	6.9	4838
1.7	4872	4.5	4859	7.1	4837
1.9	4871	4.7	4858	7.3	4834
2.1	4870	4.9	4856	7.5	4833
2.3	4870	5.1	4854	7.7	4830
2.5	4869	5.3	4853	7.9	4828
2.7	4869				

0.4° HORIZONTAL

HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K
0.2	0.49747	3.0	0.49734	5.8	0.49698
0.6	9747	3.4	9730	6.2	9691
1.0	9747	3.8	9726	6.6	9683
1.4	9744	4.2	9722	7.0	9675
1.8	9743	4.6	9717	7.4	9667
2.2	9741	5.0	9710	7.8	9658
2.6	9738	5.4	9704		

0.6° HORIZONTAL

HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K
0.3	0.31462	3.3	0.31460	5.7	0.31455
0.9	1462	3.9	1459	6.3	1453
1.5	1462	4.5	1458	6.9	1452
2.1	1461	5.1	1456	7.5	1450
2.7	1460				

0.8° HORIZONTAL

HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K
0.4	0.31949	3.6	0.31946	6.0	0.31939
1.2	1949	4.4	1944	6.8	1936
2.0	1948	5.2	1941	7.6	1932
2.8	1947				

1.0° HORIZONTAL

HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K
0.5	0.32437	3.5	0.32432	6.5	0.32421
1.5	2436	4.5	2429	7.5	2416
2.5	2435	5.5	2426		

SPACING 1.0° VERTICAL

0.1° HORIZONTAL

HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K
0.05	0.43046	2.75	0.43043	5.45	0.43032
0.15	3046	2.85	3042	5.55	3032
0.25	3046	2.95	3042	5.65	3031
0.35	3046	3.05	3042	5.75	3031
0.45	3046	3.15	3042	5.85	3030
0.55	3046	3.25	3041	5.95	3030
0.65	3046	3.35	3041	6.05	3029
0.75	3046	3.45	3041	6.15	3029
0.85	3046	3.55	3040	6.25	3028
0.95	3046	3.65	3040	6.35	3028
1.05	3046	3.75	3040	6.45	3027
1.15	3046	3.85	3039	6.55	3026
1.25	3045	3.95	3039	6.65	3026
1.35	3045	4.05	3039	6.75	3025
1.45	3045	4.15	3038	6.85	3024
1.55	3045	4.25	3038	6.95	3024
1.65	3045	4.35	3037	7.05	3023
1.75	3045	4.45	3037	7.15	3023
1.85	3045	4.55	3037	7.25	3022
1.95	3044	4.65	3036	7.35	3021
2.05	3044	4.75	3036	7.45	3021
2.15	3044	4.85	3035	7.55	3020
2.25	3044	4.95	3035	7.65	3019
2.35	3044	5.05	3034	7.75	3018
2.45	3043	5.15	3034	7.85	3018
2.55	3043	5.25	3033	7.95	3017
2.65	3043	5.35	3033		

0.2° HORIZONTAL

HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K
0.1	0.46092	2.9	0.46084	5.5	0.46064
0.3	6092	3.1	6084	5.7	6062
0.5	6092	3.3	6082	5.9	6060
0.7	6092	3.5	6081	6.1	6058
0.9	6092	3.7	6080	6.3	6056
1.1	6092	3.9	6078	6.5	6053
1.3	6090	4.1	6077	6.7	6051
1.5	6090	4.3	6075	6.9	6048
1.7	6090	4.5	6074	7.1	6046
1.9	6089	4.7	6072	7.3	6043
2.1	6088	4.9	6770	7.5	6041
2.3	6088	5.1	6068	7.7	6037
2.5	6086	5.3	6066	7.9	6035
2.7	6086				

0.4° HORIZONTAL

HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K
0.2	0.31218	3.0	0.31217	5.8	0.31212
0.6	1218	3.4	1216	6.2	1211
1.0	1218	3.8	1216	6.6	1210
1.4	1218	4.2	1215	7.0	1209
1.8	1218	4.6	1215	7.4	1208
2.2	1218	5.0	1214	7.8	1207
2.6	1217	5.4	1213		

0.6° HORIZONTAL

HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K
0.3	0.31828	3.3	0.31825	5.7	0.31819
0.9	1828	3.9	1824	6.3	1817
1.5	1827	4.5	1822	6.9	1815
2.1	1827	5.1	1820	7.5	1812
2.7	1826				

SPACING 1.0° VERTICAL

0.8° HORIZONTAL

HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K
0.4	0.32437	3.6	0.32432	6.0	0.32424
1.2	2436	4.4	2430	6.8	2420
2.0	2436	5.2	2427	7.6	2416
2.8	2434				

1.0° HORIZONTAL

HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K
0.5	0.33046	3.5	0.33041	6.5	0.33027
1.5	3045	4.5	3037	7.5	3020
2.5	3043	5.5	3032		

SPACING 2° VERTICAL

2° HORIZONTAL

HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K
1	0.21122	31	0.21104	61	0.2359
3	122	33	102	63	55
5	121	35	100	65	51
7	121	77	097	67	48
9	120	39	095	69	44
11	120	41	092	71	40
13	119	43	089	73	36
15	118	45	086	75	32
17	116	47	083	77	27
19	115	49	080	79	23
21	114	51	077	81	19
23	112	53	073	83	15
25	110	55	070	85	11
27	108	57	066	87	06
29	107	59	063	89	02

5° HORIZONTAL

HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K
2.5	0.23046	32.5	0.22570	62.5	0.21406
7.5	3020	37.5	2416	67.5	1166
12.5	2970	42.5	2246	72.5	0918
17.5	2906	47.5	2060	77.5	658
22.5	2814	52.5	1856	82.5	396
27.5	2702	57.5	1638	87.5	134

10° HORIZONTAL

HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K
5	0.26066	35	0.24986	65	0.22572
15	5876	45	4306	75	1576
25	5576	55	3494	85	0530

SPACING 5° VERTICAL

5° HORIZONTAL

HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K
2.5	0.2760	32.5	0.2642	62.5	0.2352
7.5	755	37.5	604	67.5	291
12.5	744	42.5	562	72.5	229
17.5	726	47.5	514	77.5	165
22.5	704	52.5	463	82.5	099
27.5	676	57.5	409	87.5	033

10° HORIZONTAL

HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K
5	0.015165	35	0.012465	65	0.26430
15	14690	45	10765	75	3940
25	13790	55	08735	85	1325

SPACING 10° VERTICAL

10° HORIZONTAL

HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K	HORIZONTAL ANGLE AND SETTING	K
5	0.0304	35	0.0249	65	0.0129
15	294	45	214	75	076
25	276	55	174	85	026

MANUFACTURERS' REFERENCE DATA

The content of the Manufacturers' Reference Data Section has been carefully reviewed for compliance with the specifications and standards established by the Illuminating Engineering Society for such information. The data contained herein has been provided by the individual contributors of this section. The authenticity and accuracy of such data are the responsibility of each company.

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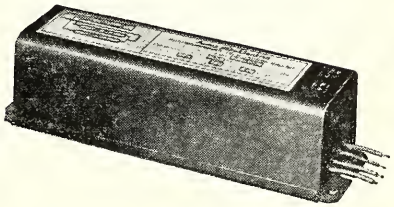
Acme Electric

Cuba, NewYork

● FLUORESCENT LAMP BALLASTS

TYPES AVAILABLE

Quick Start, Bottom Lead, End Lead, Universal Lead. 40 to 100 watts for Dual, Triple and Four Lamp Fixtures.

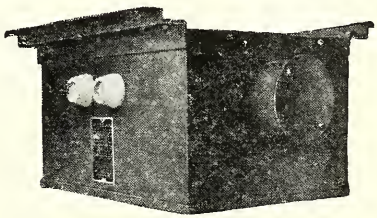


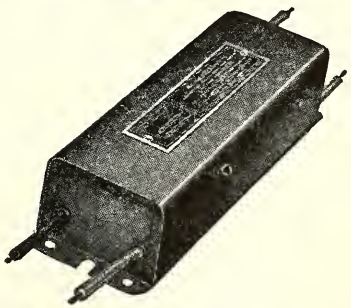
CONSTRUCTION

Cores of annealed silicon steel. Coils impregnated with polymerizing varnish. $\frac{1}{32}$″ type HR leads. Assembled case is potted with bituminous compound having thermal conductivity of 0.0045 watts/OC/CM. Softening point of compound 255°F. Write for Bulletin FL.

● COLD CATHODE LIGHTING TRANSFORMERS AND BALLASTS

For series lighting installations, transformers with secondary current ratings from 60 to 120 MA and secondary voltages of 5000 to 12000 volts are used. Tube footages from 40 to 100 ft. may be powered by a single transformer. For multiple operation of dual 93″ cold cathode fluorescent tubes, Two-Lamp Ballasts are available. *Construction:* cores, coils and assembly are processed exactly like fluorescent lamp ballasts. For performance data, refer to "Transformers and Ballasts for Cold Cathode Lighting Installation," E. A. Miller, Vol. XL-8 p. 697 Illuminating Engineering or write for Bulletin.





ACME ELECTRIC CORPORATION

CUBA, N. Y.

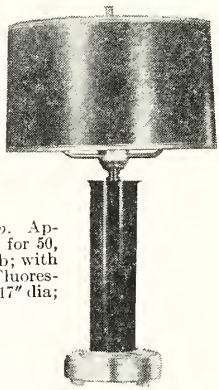
M-3

ADMIRAL LAMP MFG. CORP.

1276 Merchandise Mart, **Chicago**



9-912–*Floor Lamp.* Approximately 59″; for 100, 200, 300 watt bulb; with 32 watt Circline Fluorescent tube; shade 19″ dia; 45 footcandles.



9-421–*Table Lamp.* Approximately 28″; for 50, 100, 150 watt bulb; with 32 watt Circline Fluorescent tube; shade 17″ dia; 35 footcandles.



9-524–*Floor Lamp.* Approximately 59″; for 100, 200, 300 watt bulb; shade 19″ dia; 30 footcandles.

The above foot candle measurements for floor lamps are based on a distance of 26″ from the center of the lamp, 26″ from the floor to the center of the reading plane, at an angle of 45°.



9-404–*Table Lamp.* Approximately 25″; for 50, 100, 150 watt bulb; 20 footcandles; shade 17″ dia.



4239–*Desk Lamp.* Approximately 23″; with 15½″ metal mushroom shade, for 32 watt Circline Fluorescent tube; 75 footcandles.



9-812–*Double Swing Bridge Lamp.* Approximately 56″; for 50, 100 and 150 watt bulb; shade 16″ dia; 20 footcandles.

The above foot candle measurements for table lamps are based on a distance of 16″ from the center of the lamp, 26″ from the floor to the center of reading plane, at an angle of 45°.

The above footcandle measurements for floor lamps are based on a distance of 26″ from the center of the lamp, 26″ from the floor to the center of the reading plane, at an angle of 45°.

Our Fluorescent lamps have the following features:

1. Minimizing of radio interference.
2. Quick starting.
3. Proper air circulation that will keep ballast cool at all times.
4. Four-wire system to prevent any leakage of current.

Send us your Inquiry

* * * * *

ADMIRAL CERTIFIED LAMPS
ALL LAMPS ARE CONSTRUCTED TO CONFORM TO CLM SPECIFICATIONS

Illumination Data from Test in Company Laboratory.

ADVANCE TRANSFORMER CO.

1136 W. Catalpa Ave.
Chicago 40, Ill.



Our ballasts are vacuum varnish impregnated, and sealed with special high temperature potting compound to eliminate moisture and insure quietness. We manufacture a complete line of hot cathode and cold cathode ballasts for 50 and 60 cycles, all common voltages and all residential, commercial and industrial sizes. Ballasts are constructed on the "Long John" principle to give minimum height. All ballasts are Underwriters' Laboratories approved and some are certified by the Electrical Testing Laboratories Inc.

CAT. NO.	SIZE & NO. LAMPS	POWER FACTOR*	LINE CURRENT
RSL-122	1—22 Watt (Circline)	N	.39
L-115	1—15 Watt	N	.32
L-120	1—20 Watt	N	.36
L-215	2—15 Watt	N	.70
L-220	2—20 Watt	N	.72
RSH-115	1—15 Watt	H	.19
RSH-120	1—20 Watt	H	.23
RSL-130	1—30 Watt	N	.72
RSH-130	1—30 Watt	H	.36
L-140	1—40 Watt	N	.75
RSH-140	1—40 Watt	H	.50
RSL-132†	1—32 Watt** (Circline)	N	.60
S-240	2—40 Watt	H	.85
RSH-240†	2—40 Watt	H	.85
RSH-232	2—32 Watt (Circline)	H	.70

The above list of ballasts are also made in the following combinations:

VOLTAGE	FREQUENCY	CATALOGUE	
110–125	50	RTL	Normal P. F.
		RTH	High P. F.
220 (208–236)††	60	XSL	
		XSH	
220 (208–236)††	50	XTL	
		XTH	
208 (199–216)††	60	WSL	
		WSH	
208 (199–216)††	50	WTL	
		WTH	
236 (225–245)††	60	YSL	
		YSH	
236 (225–245)††	50	YTL	
		YTH	

* N—Normal P. F.
H—90% or better P. F.
** In long can same as 1-40.

† ETL certified.
†† Also include High P. F. 2-30.

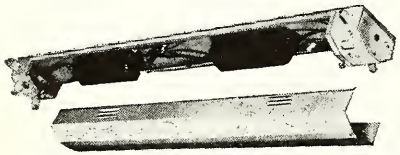
ALL-BRIGHT ELECTRIC PRODUCTS COMPANY

Manufacturers of Fluorescent Lighting Fixtures

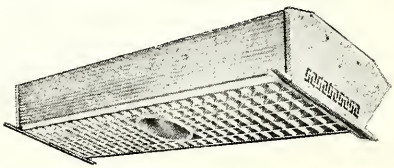
3917-25 N. Kedzie Ave. Chicago 18, Illinois

LIGHT RIGHT WITH All-bright

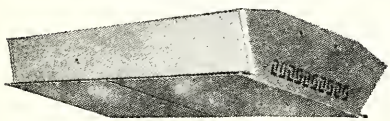
SURFACE MOUNTED LUMINAIRES



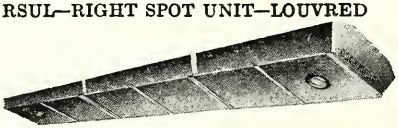
BCU—BASIC COMMERCIAL UNIT



RSUL—RIGHT SPOT UNIT—LOUVRED



RU—SKYLIGHT UNIT



RSU AND RU—COMBINATION

(1) B. C. U.—BASIC COMMERCIAL UNIT—with provisions for suspension mounting. Sturdy, heavy gauge steel, reinforced. Special reflector for direct light can be secured on application. Can be furnished with or without standard base adjustable sockets for spot or flood lamp.

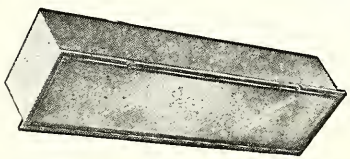
(2) R. U.—SKYLIGHT UNIT—consists of Basic Commercial Unit with Alba-Lite or Ceramic side panels and Alba-Lite or clear ribbed Skytex bottom glass or full depth metal eggcrate Louvre.

(3) R. S. U. L.—RIGHT SPOT UNIT—Louvred—combination of fluorescent and incandescent, consists of Basic Commercial Unit with adjustable standard base socket (an integral part) for use with two 100 watt T-17 fluorescent lamps and 5¼ inch opening in metal eggcrate Louvre for use with PAR-38 lamp.

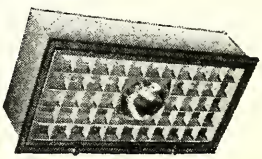
(4) R. S. U. and R. U.—Combination continuous SKYLIGHT and RIGHT SPOT consists of four BCU-404 units two of which are equipped with adjustable standard sockets and 5¼ inch opening in bottom of glass for use with PAR-38 lamp.

(5) Surface mounted units may be used in various combinations of either individual units or continuous rows in which two ends only are required. A special open through bracket is provided for the intermediate luminaires eliminating dark spots on the fixture.

RECESSED TYPE LUMINAIRES



REC—RECESSED UNIT—INDIVIDUAL



RSUL—RIGHT SPOT COMPENSATING UNIT—LOUVRED



REC—RECESSED UNIT—CONTINUOUS



RSU—RIGHT SPOT UNIT—CONTINUOUS

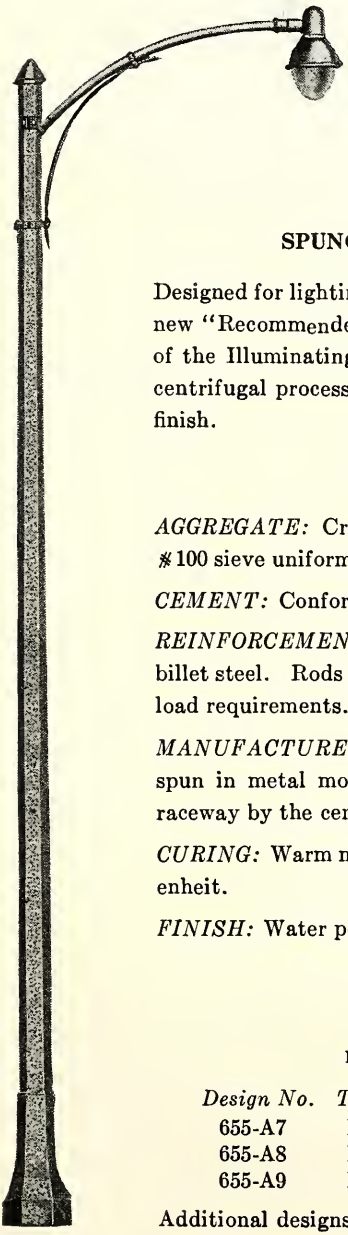
(6) R. E. C.—RECESSED PIANO HINGED UNITS—two, three, and four lamp 20 watt, 24 inches long. Two, three, and four lamp 40 watt, 48 inches long. Two lamp 100 watt, 60 inches long.

All Illumination Data from test by Company Laboratory.

AMERICAN CONCRETE CORPORATION

4727 North Lamon Avenue
Chicago 30, Illinois

Manufacturers of "Spuncrete" lighting standards for streets, bridges, and highways.



SPUNCRETE LIGHTING STANDARDS

Designed for lighting systems which meet the requirements of the new "Recommended Practice of Street and Highway Lighting" of the Illuminating Engineering Society. Manufactured by the centrifugal process, with water polished black and white granite finish.

ENGINEERING DATA

AGGREGATE: Crushed black and white granite or marble $\frac{3}{8}$" to #100 sieve uniformly graded.

CEMENT: Conforms to latest A.S.T.M. specifications.

REINFORCEMENT: Meets A.S.T.M. specifications for rail or billet steel. Rods held in tension with sufficient steel area to meet load requirements.

MANUFACTURE: A properly designed mixture of concrete is spun in metal molds to produce a dense concrete and a cable raceway by the centrifugal action.

CURING: Warm moist steam curing not exceeding 175 deg. Fahrenheit.

FINISH: Water polished Terrazzo finish to reveal the aggregate.

HY-LITE DESIGN (Illustrated)

Design No.	*Type of Base*	*Mounting Ht.*	*Bracket Spread*
655-A7	Bolt down	21–6	Single 6′ Arm
655-A8	Bolt down	26–6	Single 6′ Arm
655-A9	Bolt down	31′6	Single 6′ Arm

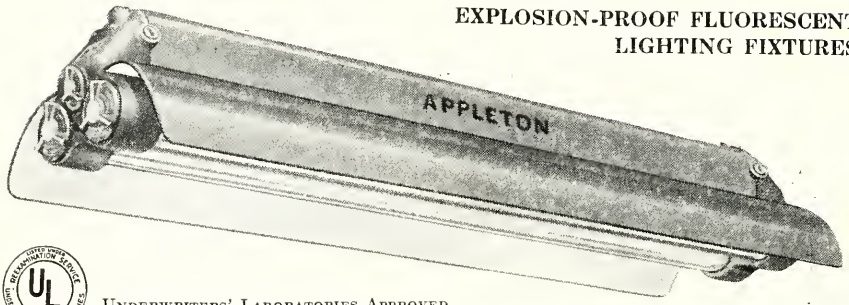
Additional designs on request.

APPLETON ELECTRIC COMPANY

1751 Wellington Avenue, Chicago 13, Illinois

14 Branch Offices and 7 Resident Representatives in All Principal Markets

EXPLOSION-PROOF FLUORESCENT LIGHTING FIXTURES



UNDERWRITERS' LABORATORIES APPROVED

Patented Jan. 1, 1946—Patent 2, 392, 202

TWO SIZES:

Two 40-Watt, 48-Inch T-12 Lamps

Two 100-Watt, 60-Inch T-17 Lamps

Underwriters' Laboratories Approved for all hazardous locations in Class I, Groups C and D, and Class II, Groups E, F and G.

Used in oil refineries, hospital surgeries, chemical plants, grain elevators, wherever flammable gases or dusts are present.

Lamps are located inside Pyrex glass tubes, which are internally sealed at the factory for complete, permanent explosion-proof protection. Equipment includes high power-factor, two-lamp ballast; all necessary auxiliary equipment, and two-piece steel reflector—inside white, outside gray. Detailed light distribution data sent on request.

End wiring chambers are cast aluminum with completely explosion-proof screw covers for access.

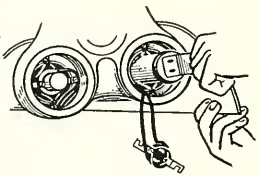
LINE CONNECTION

Connecting block for line connection located conveniently inside upper explosion-proof screw cover. No other electrical connections are made on the job.



STARTERS

Starters just inside lower explosion - proof screw covers can be replaced without removing lamps. Relamping is quick and easy.



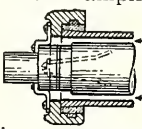
BALLAST



Ballast mounted in explosion-proof housing at center of unit, under outer dust cover, is quickly accessible. Flexible coupling relieves any possible strain on Pyrex glass tubes.

LAMP SUSPENSION

Lamps are held in position in center of Pyrex tubes by springs which also facilitate re-lamping.



Workmanlike hanging is facilitated by use of Appleton flanged ceiling "Unilets" with fixture canopy, "dead-end" ceiling supports, and union connectors. Appleton Types "ESD" and "ESS" Swivels permit hanging in conformance to all code requirements. Two hubs for 45° suspension are provided.

For complete data and other information, contact Engineering Department at above address.

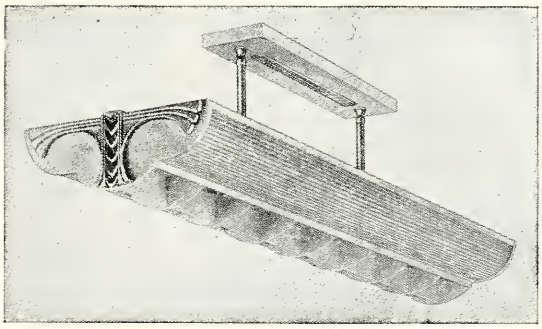
COMPLETE LINE

The Appleton Explosion-Proof Fluorescent Lighting Fixture is only one of the complete Appleton line, including all types of Explosion-Proof, Dust-Tight and Vaportight Lighting Fixtures. Altogether, Appleton manufactures more than 15,000 types and sizes of conduit fittings, outlet and switch boxes and other wiring materials. Complete catalog on request.

THE ART METAL COMPANY

Cleveland 3, Ohio

Manufacturers of Engineered Lighting and Ultraviolet Germicidal Equipment



DESCRIPTION

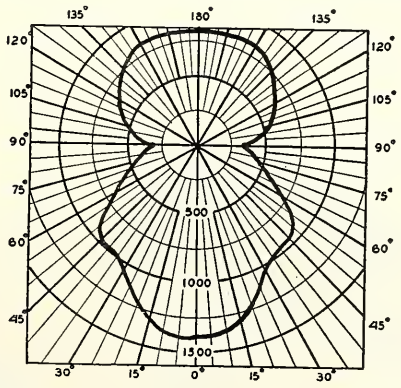
The Paralier system is available in two or four light arrangements for either close ceiling or suspension mounting and for individual or continuous row installation. Frames are hinged for ease of maintenance, louvers and fluted diffusing glass are removable. Suspension units have chrome twin-swivel hangers. Finish is Silvwhite with cast polished aluminum end plates.

PERFORMANCE

The Paralier system is precisely engineered for controlled illumination with high efficiency and widespread distribution. Paralier shielding directs 53% of the luminaire output downward and 47% upward. The shielding angle is 60° to provide adequate protection at all normal viewing ranges. Fluted glass side panels have good diffusing characteristics and limit surface brightness to 1.5 candles per square inch in 4 light units—with less than 1 candle on the 2 light units.

SPECIFICATIONS

Paralier ballast compartments, frames and canopies, are of heavy gauge steel. Butt-on lamp holders are attached to steel frame which is welded to ballast compartment for perfect and permanent lamp alignment. Wiring and accessories accessible through removable reflector plate. Steel framing strips hold glass sides. Chrome plated hangers are equipped with self-aligning swivels. Ballasts are 110–125V 60 cycle AC. High power factor starters are FS 4.



DISTRIBUTION CURVE—PARALIER 4 LIGHT UNIT

Illumination Data from Test in Company Laboratory

BRIGHT LIGHT REFLECTOR CO.

Fairfield & State, Bridgeport 5, Conn.

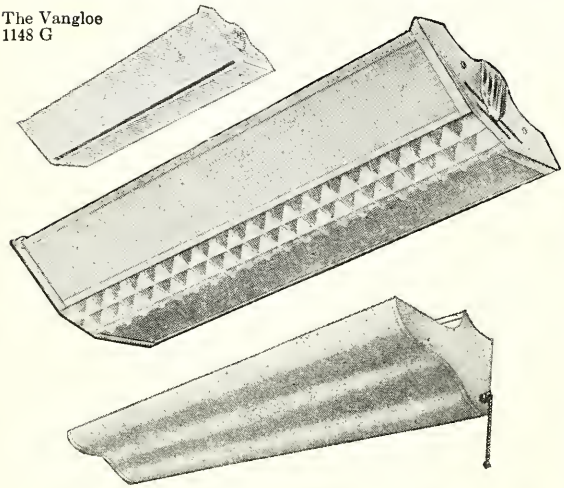
Atlanta, Ga.
Baltimore, Md.
Boston, Mass.
Chicago, Ill.
Cleveland, Ohio
Dallas, Texas
Denver, Col.
Detroit, Mich.
Indianapolis, Ind.

SILV-A-KING LIGHTING EQUIPMENT

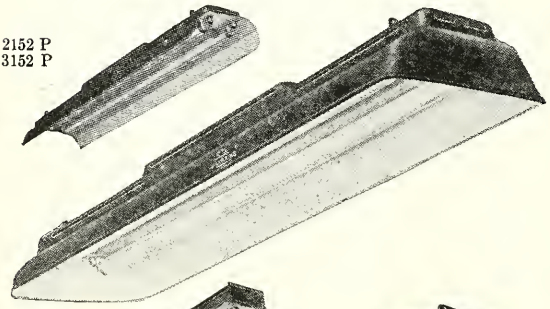
Kansas City, Mo.
Los Angeles, Cal.
Minneapolis, Minn.
New York, N. Y.
Philadelphia, Pa.
Pittsburgh, Pa.
San Francisco, Cal.
Seattle, Wash.
St. Louis, Mo.

FLUORESCENT COMMERCIAL & INDUSTRIAL UNITS

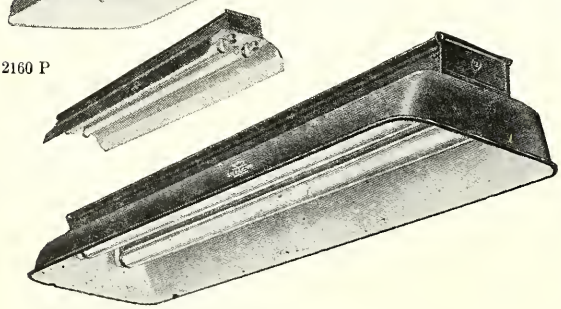
The Vangloe
1148 G



2152 P
3152 P



2160 P



COMMERCIAL UNITS

The Vanguard "Fleur-o-lier approved"
2148 GL (4 lamp 40 watt)

A commercial luminaire that meets the most exacting requirements, for either suspension or surface mounting, installed as individual units or in rows. Modified V design, with slotted ends, egg crate louvres, and side panels of frosted, ribbed glass, hinged at the top for easy access.

GERMICIDIAL UNITS

GR 18C (15 watt) GR 36C (30 watt)

To purify the air in homes, schools, offices, or factories, these units provide ultra-violet radiation that destroys airborne bacteria. Safe, modern in design, easy to install, these fixtures utilize Standard Germicidal Lamps.

INDUSTRIAL UNITS

RLM Specification
7152 P (2 lamp 40 watt)
8152P (3 lamp 40 watt)

Fluorescent luminaires in porcelain enamel, with features adapted to the most rigid installation requirements: reflector and hood are one-piece, drawn, seamless, non-welded construction; all operating equipment in hood; starters instantly accessible; all wiring I.B.E.W.; ballasts E.T.L. certified; all units U. L. approved.

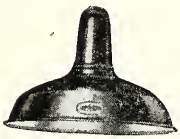
RLM Specification
7160 P (2 lamp 100 watt)

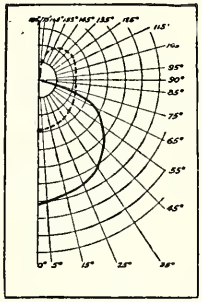
Available in a wide range of ratings and mounting types—for hanger, conduit, or chain suspension—either individually or in rows.

BRIGHT LIGHT REFLECTOR CO.

INCANDESCENT LIGHTING EQUIPMENT

Standard Dome Reflectors

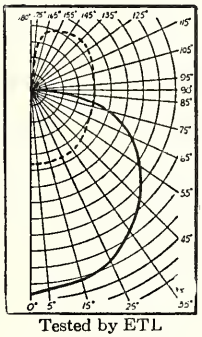


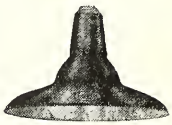


Wattage	Reflector Dia.
†75/100*	12″
†150*	14″
†200*	16″
300/500	18″
750/1500	20″

Tested by ETL

Shallow Dome Reflectors



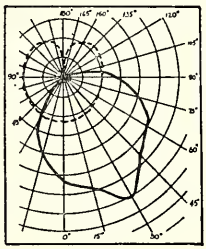


Wattage	Reflector Dia.
†75/100*	12″
†150*	14″
†200*	16″
300/500	18″

Tested by ETL

Symmetrical Angle Reflectors

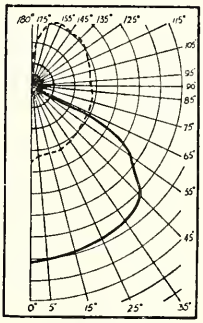




Wattage	Reflector Dia.
†100*	8″
†150*	10″
†200	12″
300/500	14″
750/1500	16″

Tested by ETL

Deep Bowl Reflectors





Wattage	Reflector Dia.
†75/100*	8″
†100/200*	10″
300/500	12″
750/1500	16″

Tested by ETL

All of the Above Units are Available with Speed-lox Necks

* The above units are available with shades-holders necks

† The above units are available with pull-chain sockets



Speed-Lox

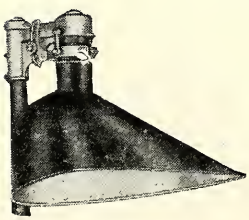


Solid Neck

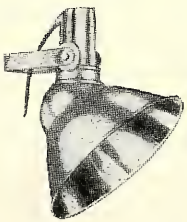


Shade Holder

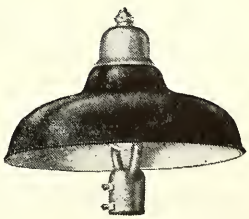
FLOODLIGHTS and ISLAND LIGHTS



"Super-Service"



"Sport-Area



"Island Light

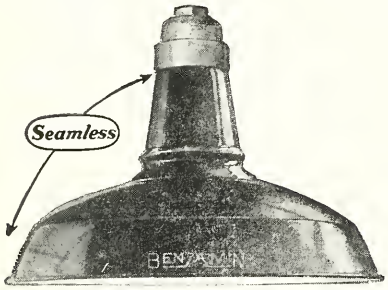
Benjamin Electric Manufacturing Company

Des Plaines (Chicago Suburb) Illinois

20 North Wacker Drive
Chicago 6, Illinois

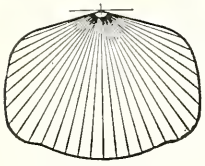
Divisional Sales Office
230 West 17th Street
New York 11, New York

448 Bryant Street.
San Francisco 7, Calif.



RLM DOME REFLECTOR

Benjamin RLM Dome Porcelain Enameled Steel Reflectors are made in sizes to accommodate 75 to 1500-watt incandescent lamps. They have either separable "Socket-Reflector" fittings or "Turnlox" detachable, pendent, ceiling or angle type hoods. Mean light output of all reflectors is 78% or more, except 100 watt size which is 75% or more. The lamp filament center is shielded from view to 17½° below the horizontal. As indicated in typical curve at left these reflectors illuminate vertical surfaces very effectively.



Typical Curve

Spacing distance between reflectors should never exceed one and one-half times the mounting height.

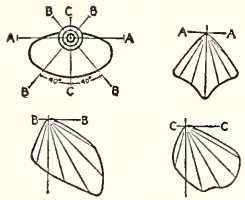
TABLE OF COEFFICIENTS OF UTILIZATION

Ceiling	75%			50%			30%	
Walls	50%	30%	10%	50%	30%	10%	30%	10%
Room Index								
J	.35	.30	.25	.35	.30	.25	.29	.25
I	.43	.39	.35	.43	.38	.34	.38	.34
H	.47	.44	.40	.46	.43	.40	.43	.40
G	.52	.48	.44	.50	.47	.44	.46	.43
F	.55	.52	.47	.54	.50	.47	.49	.46
E	.60	.57	.53	.59	.56	.53	.55	.53
D	.64	.61	.58	.63	.60	.58	.60	.58
C	.66	.63	.60	.65	.62	.60	.62	.60
B	.69	.67	.65	.68	.66	.64	.65	.63
A	.71	.69	.67	.69	.68	.66	.67	.65



ELLIPTICAL ANGLE REFLECTOR

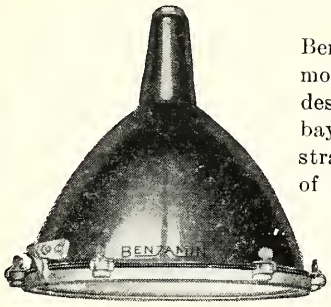
Benjamin Elliptical Angle Porcelain Enameled Steel Reflectors are available in sizes to accommodate 75 to 1500-watt incandescent lamps. Units are furnished with a choice of separable "Socket-Reflector" fittings or "Turnlox" detachable, pendent, ceiling or angle type hoods. The lamp filament is shielded from view to 17½° below the horizontal. This unit has proven to be an effective method of providing general illumination where overhead lighting is impractical or inadequate.



Typical distribution curves made on perpendicular planes through lines marked AA, BB and CC.

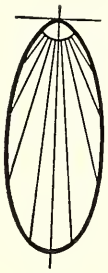
TABLE OF COEFFICIENTS O F UTILIZATION

Ceiling	75%			50%			30%	
Walls	50%	30%	10%	50%	30%	10%	30%	10%
Room Index								
J	.32	.27	.23	.32	.27	.23	.26	.23
I	.39	.35	.32	.39	.33	.31	.34	.31
H	.42	.40	.36	.41	.39	.36	.39	.36
G	.47	.43	.40	.45	.42	.39	.41	.39
F	.50	.47	.42	.49	.45	.42	.44	.41
E	.54	.51	.48	.53	.50	.48	.50	.48
D	.58	.55	.52	.57	.54	.52	.54	.52
C	.59	.57	.54	.59	.56	.54	.56	.54
B	.62	.60	.59	.61	.59	.58	.59	.57
A	.64	.62	.60	.62	.61	.59	.60	.59



"STEELITE" ARMOR-CLAD LIGHTING UNITS

Benjamin vapor tight, "Steelite" lighting units accommodate 750 to 1500 watt incandescent lamps and are designed to provide general illumination in high-bay areas, where units are subjected to mechanical strain and severe atmospheric conditions. Three types of Alzak aluminum reflectors are available with the following efficiencies: Narrow beam 71%; Concentrating 66%; Spread 72½%. Unit housing is porcelain enameled steel with a hinged, impact-resisting plate glass cover; fittings are separable, "Socket-Reflector" type.

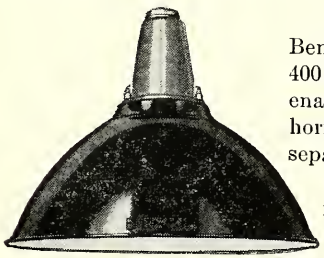


Typical Curve
Concentrating Refl.

TABLE OF COEFFICIENTS OF UTILIZATION*

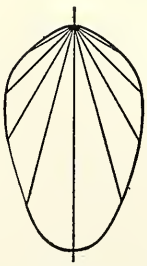
Ceiling	75%			50%			30%	
Walls	50%	30%	10%	50%	30%	10%	30%	10%
Room Index								
J	.38	.36	.34	.38	.36	.34	.37	.34
I	.45	.43	.42	.44	.43	.42	.43	.41
H	.48	.48	.47	.47	.47	.46	.47	.45
G	.52	.51	.50	.51	.50	.49	.50	.48
F	.55	.53	.52	.52	.52	.51	.52	.50
E	.57	.56	.55	.56	.55	.54	.54	.53
D	.60	.58	.57	.58	.57	.56	.56	.55
C	.61	.59	.57	.59	.58	.57	.57	.57
B	.61	.60	.59	.59	.58	.58	.58	.57
A	.62	.61	.60	.60	.59	.58	.58	.58

** Data in the above table is based on the concentrating type unit with an incandescent lamp. For 400-watt Mercury, concentrating type "Steelite" multiply figures by 1.02.*



"HIGH BAY" DOME MERCURY LAMP UNIT

Benjamin 20″ Dome Type units accommodate standard 400 watt mercury lamps. The reflectors are of porcelain enameled steel with a shielding angle of 17½° below the horizontal. Units have spun steel necks and include separable "Socket-Reflector" fittings or "Turnlox" detachable, pendent, ceiling or angle hoods. Maximum spacing is 1.5 times the mounting height.

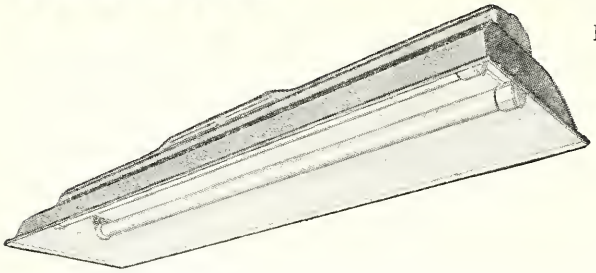


Typical Curv

TABLE OF COEFFICIENTS OF UTILIZATION†

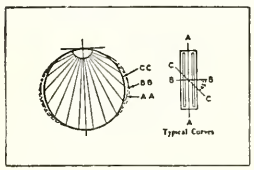
Ceiling	75%			50%			30%	
Walls	50%	30%	10%	50%	30%	10%	30%	10%
Room Index								
J	.35	.30	.25	.35	.30	.25	.29	.25
I	.43	.39	.35	.43	.38	.34	.38	.34
H	.47	.44	.40	.46	.43	.40	.43	.40
G	.52	.48	.44	.50	.47	.44	.46	.43
F	.55	.52	.47	.54	.50	.47	.49	.46
E	.60	.57	.53	.59	.56	.53	.55	.53
D	.64	.61	.58	.63	.60	.58	.60	.58
C	.66	.63	.60	.65	.62	.60	.62	.60
B	.69	.67	.65	.68	.66	.64	.65	.63
A	.71	.69	.67	.69	.68	.66	.67	.65

† For "High Bay" Dome unit with 750 to 1500-watt incandescent lamp multiply figures by .96.



RLM "STREAM-FLO 40"

Benjamin "Stream-Flo 40" units are available in either two or three 40 watt Type F lamp arrangements. The porcelain enamel reflector has a high reflection factor of 79%, and is resistant to deteriorating atmospheric conditions. Efficiency of two lamp units is 79% and of three lamp units is 72%; shielding angle is 13° below the horizontal. The steel clad safety type Springlox lampholder eliminates the hazard of lamps dropping out.

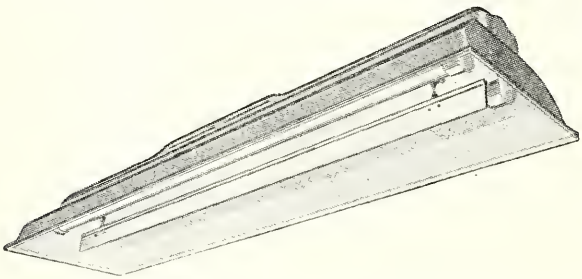


This type unit is available in a continuous line as the Benjamin "Lite-Line 40", and with open end reflectors as the "Twin-Flo 40" and "Triple-Flo 40."

TABLE OF COEFFICIENTS OF UTILIZATION*

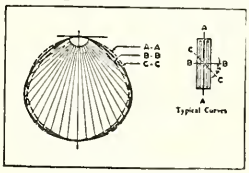
Ceiling	75%			50%			30%	
Walls	50%	30%	10%	50%	30%	10%	30%	10%
Room Index								
J	.37	.32	.28	.37	.32	.28	.31	.28
I	.46	.41	.38	.45	.40	.37	.41	.37
H	.50	.46	.43	.49	.46	.43	.45	.43
G	.54	.50	.47	.53	.50	.47	.48	.47
F	.58	.54	.50	.56	.52	.50	.52	.50
E	.62	.59	.56	.61	.58	.56	.57	.56
D	.67	.64	.60	.65	.63	.60	.62	.60
C	.69	.66	.63	.67	.64	.63	.64	.62
B	.72	.69	.67	.70	.68	.66	.67	.65
A	.74	.71	.69	.72	.69	.68	.68	.67

** Figures shown are for twin-lamp unit; for triple-lamp unit multiply these by 0.91.*



RLM "SHIELD-FLO 40"

The Benjamin "Shield-Flo 40" lighting unit, for two 40 watt Type F lamps, consists of the "Stream-Flo 40" unit plus a porcelain enameled longitudinal shield which provides a 27° shielding angle for both near and far lamps. This deeper shielded lighting unit has a minimum efficiency of 70% and is desirable for use in supplying localized and general illumination as it provides added protection against glare in the eyes of adjacent workers.

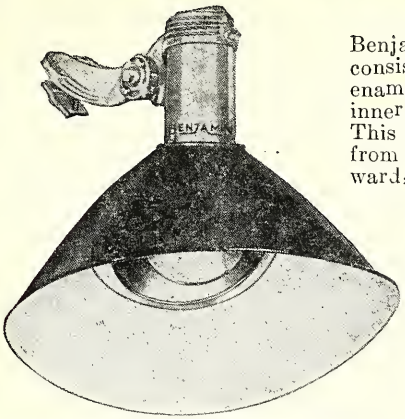


The longitudinal shield is also available for use with Benjamin continuous channel "Lite-Line 40 System", and with open end reflector "Twin-Flo 40."

TABLE OF COEFFICIENTS OF UTILIZATION

Ceiling	75%			50%			30%	
Walls	50%	30%	10%	50%	30%	10%	30%	10%
Room Index								
J	.35	.31	.28	.35	.31	.28	.30	.28
I	.43	.40	.38	.42	.39	.37	.39	.37
H	.47	.44	.42	.46	.44	.42	.43	.42
G	.51	.48	.46	.50	.47	.45	.46	.45
F	.53	.51	.48	.52	.50	.47	.49	.47
E	.57	.55	.52	.56	.54	.52	.53	.52
D	.61	.58	.56	.59	.57	.56	.57	.59
C	.63	.60	.57	.61	.59	.57	.58	.57
B	.65	.62	.61	.63	.61	.60	.60	.59
A	.66	.64	.62	.64	.62	.61	.62	.60

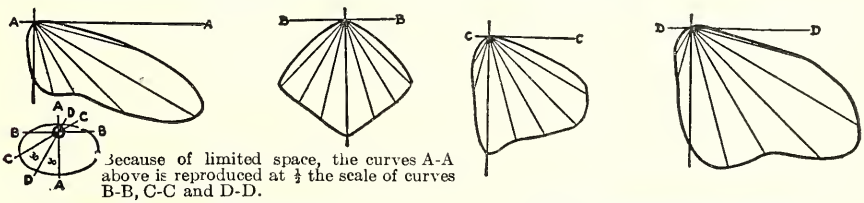
"ELLIPTO-LITE" FLOODLIGHTS



Benjamin "Ellipto-Lite" Play-Area Floodlights consist basically of a large diffusing porcelain enameled steel elliptical shaped reflector with an inner reflector of processed oxidized aluminum. This inner reflector takes a portion of the light from the lamp and directs it to points farther forward, improving illumination in more distant areas. The deep overhanging front section of the "Ellipto-Lite" floodlight provides effective shielding of the light source so that candlepower values fall off by 50% at a point less than 15° above the angle of maximum candlepower, which is well out of the normal line of vision, usually considered to be approximately 75°. Benjamin "Ellipto-Lite" Floodlights are designed for either 300–500 watt lamps or 750–1500 watt lamps. They are available with a choice of four types of mounting brackets for convenient installation.

Lighting Characteristics

Below are candlepower distribution curves of the Benjamin 750–1500 Watt "Ellipto-Lite" Floodlight. These curves are through perpendicular planes marked A-A, B-B, C-C and D-D.

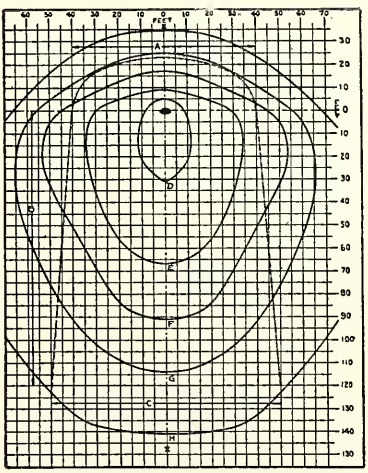


Because of limited space, the curves A-A above is reproduced at ½ the scale of curves B-B, C-C and D-D.

Data on Coverage of a Single Unit

The accompanying data on the coverage of a single floodlight will be found valuable in forming the basis for determining the locations where units should be mounted to obtain uniform illumination, adequate coverage and freedom from shadows.

DIAGRAM 2—Coverage of One Unit



NOTE—The dotted lines and curves in the diagram above indicate the area effectively covered by a single unit mounted at a height of 40 feet, with a lamp in a vertical position. For the areas effectively illuminated at other mounting heights, refer to Table 3 for dimensions A, B and C.

TABLE 3—Area Effectively Lighted Using 750–1500 Watt Size Floodlight

Mounting Height	A	B	C
20 feet	40′	60′	50′
25 feet	50′	75′	60′
30 feet	60′	90′	75′
35 feet	70′	105′	85′
40 feet	80′	120′	100′
50 feet	100′	150′	125′

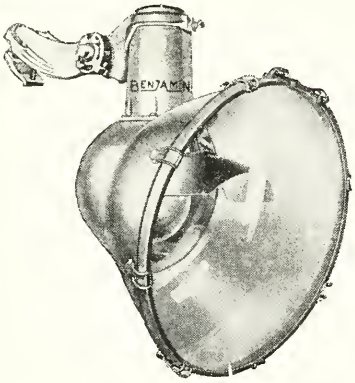
NOTE—It will be seen from the area of effective illumination shown in Diagram 2, that the spacing distance between units should never be more than twice the mounting height.

TABLE 4—Footcandles on Horizontal†

Mounting Height	Lamp Watts	D	E	F	G	H
*20 feet	750	3.1	.36	.1	.03	
	1000	4.3	.5	.14	.04	
	1500	6.9	.8	.23	.06	
*25 feet	750	2.8	.5	.22	.06	.02
	1000	3.9	.7	.3	.09	.03
	1500	6.2	1.1	.48	.15	.05
*30 feet	750	2.3	.65	.28	.1	.04
	1000	3.1	.9	.33	.14	.05
	1500	5.0	1.5	.61	.23	.08
*35 feet	750	1.8	.7	.33	.14	.06
	1000	2.5	1	.46	.2	.09
	1500	4.0	1.6	.74	.32	.15
40 feet	750	1.4	.7	.36	.18	.07
	1000	2	1	.5	.25	.1
	1500	3.2	1.6	.8	.4	.16
*50 feet	750	.94	.7	.41	.23	.09
	1000	1.3	.94	.57	.32	.12
	1500	2.1	1.5	.91	.51	.19

** NOTE—Intensities for these mounting heights are for points on the line X-X only, as shown in Diagram 2. Footcandle values in the above table are for one unit only.*

† Values based on 14,550 lumens for 750-watt, 20,000 for 1000-watt and 33,000 for 1500-watt lamps.



"ALZO-LITE" FLOODLIGHTS

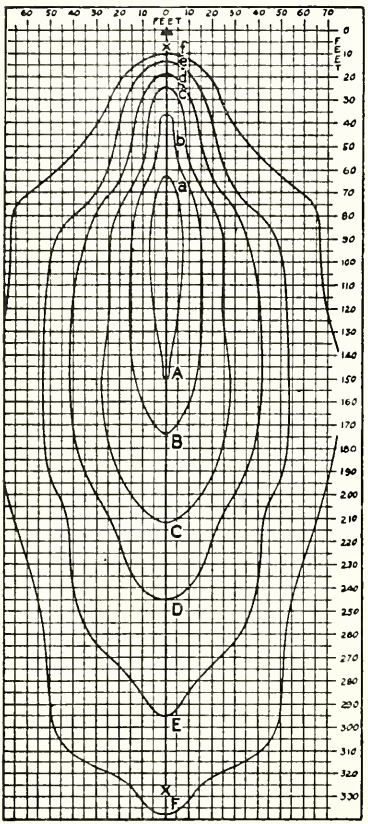
Benjamin "Alzo-Lite" floodlights, with Alzak aluminum reflectors, are made in two types of coverage. Long-Range "Alzo-Lite", as illustrated at left, is for use on poles located 55 to 150 feet away from area to be lighted, and the Benjamin Medium-Spread "Alzo-Lite" is for use on poles located from 30 to 55 feet away from area to be lighted.

The Long-Range "Alzo-Lite" accommodates an Alzak aluminum deflector which redirects a portion of spill light downward to provide additional useful illumination.

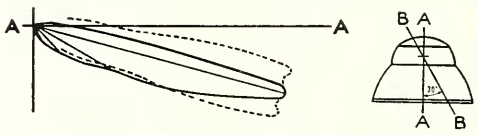
Benjamin "Alzo-Lite" floodlights are available with a water-proof, hinged glass cover which eliminates any possibility of rain, moisture, mist or fog penetrating to the interior of the floodlight and causing lamp breakage.

Floodlights can be supplied with a choice of four styles of mounting brackets.

The coverage data below, applies to a single Long-Range type floodlight with deflector.



The curves in the diagram above, in conjunction with Table 2, indicate intensities of illumination horizontally on the area from one unit mounted at a height of 70 feet.



Typical Curves

Curve A-A above is $\frac{1}{10}$ the scale of B-B. Dotted line curve is at 90° to plane A-A and at angle of maximum candlepower.

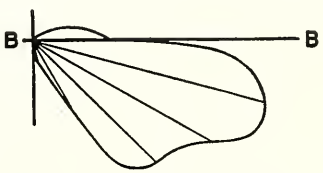


TABLE 2—Footcandles on Horizontal Plane at Ground Level†

Mtg. Hgt.	Lamp Watts	f	e	d	c	b	a
*50′	1500	.28	.34	.57	.79	1.36	1.34
*60′	1500	.14	.21	.37	.52	.84	.93
70′	1500	.1	.2	.3	.4	.5	.6
*80′	1500	.06	.09	.14	.19	.37	.53

(Table continued below)

Mtg. Hgt.	Lamp Watts	A	B	C	D	E	F
*50′	1500	.8	.62	.33	.15	.06	.03
*60′	1500	.76	.65	.45	.28	.13	.06
70′	1500	.6	.5	.4	.3	.2	.1
*80′	1500	.52	.47	.39	.31	.21	.13

To obtain footcandle values for 750 watt lamp multiply by .44, and for 1000 watt lamp multiply by .64.

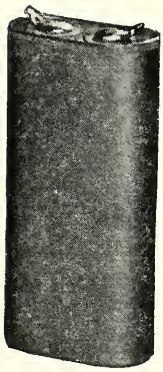
* NOTE—Footcandle values in above table for mounting heights of 50′, 60′ and 80′ are for points on the line X-X only, and are for one unit only with lamp in vertical position. Intensities shown in the table are for units less glass cover; when using cover multiply above values by .88.

† Intensities based on 14,550 lumens for 750-watt, 21,000 for 1000-watt and 33,000 for 1500-watt lamps.
Data on RLM units obtained from tests of Electrical Testing Laboratories Inc.; balance of data from tests made at Benjamin's Testing and Development Laboratory.

THE CAPACITRON COMPANY, INC.

849 North Kedzie Avenue, Chicago 51, Illinois

Fluorescent Ballast Capacitors with "TORRIDOL"

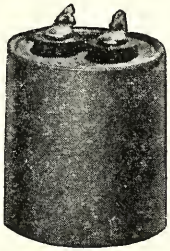


Type GA

Rectangular

Type BAR

Not Illustrated



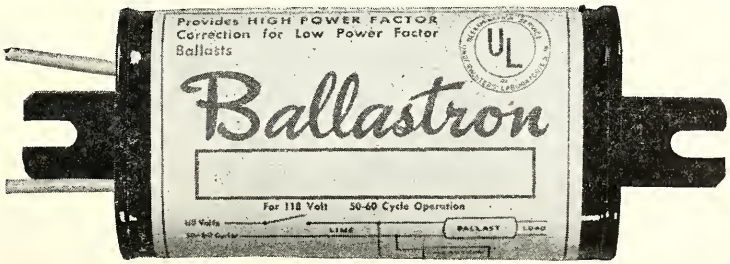
Type FA

"TORRIDOL" impregnant will not burn and withstands heat up to 600°F without chemical change or decomposition. All Capacitrons have riveted type terminal assembly—fully assembled and specially treated prior to mounting on capacitor. Containers are lead coated steel. Covers are sealed on automatically —first mechanically and then by automatic soldering machine. Thus, sealing of cover does not depend on solder alone.

Other capacities and voltages available in types listed below. Capacity Tolerance is ∓6%.

Type	Cat. No.	Cap. Mfd.	Volts A.C.
GA	2GA390	3.9	220
GA	2GA475	4.75	220
GA	3GA390	3.9	330
FA	3FA300	3.	330
FA	3FA350	3.5	330
FA	5FA175	1.75	550
FA	5FA190	1.9	550
FA	6FA175	1.75	660
BAR	2BAR1700	17.	220
BAR	2BAR1400	14.	220

BALLASTRONS—High Power Factor Correction Units to be used on Fixtures Having Low Power Factor Ballasts



Mounts Inside of Fixture Housing . . . Only Two Wires to Connect . . . Can be Used on Fixtures Already Wired

BALLASTRONS are designed to fit all Standard fixtures and come complete with mounting hardware. They connect in parallel across the A.C. Line

BALLASTRONS are Available in Sizes For Use with 1 to 4 Fluorescent Lamps in Sizes 15 to 40 Watts at Voltages of 118 and 236, for 25, 50 and 60 Cycles.

CHAMPION LAMP WORKS

LYNN, MASSACHUSETTS
A DIVISION OF CONSOLIDATED ELECTRIC LAMP CO.

INCANDESCENT FLUORESCENT INFRARED GERMICIDAL

CHAMPION INCANDESCENT LAMPS

GENERAL SERVICE lamps fulfill most of the lamp requirements for homes, stores, offices, schools, factories and institutions. Designed for use on 115–120–125 volt circuits in sizes 15 to 1500 watts, and for 230–250 volt circuits in sizes 25 to 1000 watts.

INSIDE FROSTED lamps (15 to 1000 watts) are used in most fixtures for lamps up to 100 watts in size. In higher wattages, inside frosted lamps are generally used with direct, semi-indirect, or indirect fixtures when diffusion and soft shadows are desired.

CLEAR lamps (150 to 1500 watts) are used where some control of light distribution is required such as in fixtures having polished or lightly etched reflecting surfaces or in prismatic glass fixtures to obtain designed light distribution.

INSIDE WHITE BOWL lamps (150 to 500 watts) are for use in open type reflectors. The white bowl shields the filament and reduces glare.

SILVERED BOWL lamps (60 to 500 watts) are designed for indirect lighting in fixtures designed especially for use with these lamps.

DAYLIGHT lamps (60 to 500 watts) are of special blue glass to produce light approximating average daylight quality.

Champion Incandescent Lamps include lamps for rough service, vibration service, floodlight, spotlight, projection service, street series, street railway, traffic signal, train, locomotive and country home service. Tubular and lumiline lamps, reflector floodlight and spotlight lamps, colored, decorative and sign lamps are also available.

CHAMPION FLUORESCENT LAMPS

For use only with auxiliary equipment designed to produce proper electrical values.

Champion Fluorescent Lamps are available in all standard sizes, 14 watts to 100 watts; 6 and 8 watt in 3500° White; 14 watt in 3500° White and 4500° White; Daylight, 3500° White, 4500° White and Soft White in all other sizes. Colors Blue, Green, Pink, Gold and Red available in 15 watt T8, 20, 30 and 40 watt lamps.

Instant start 3500° White lamps are available in the 40 watt size.

Slimline lamps in 42″, 64″, 72″ and 96″ lengths for operation at 100 or 200 milliamperes current and Circline lamps in 8½″, 12″ and 16″ diameters will be announced when available.

Call your nearest Champion distributor or write the factory for Manufacturers' Schedule and complete information on any or all lamps.

CHICAGO MINIATURE LAMP WORKS

1500 North Ogden Avenue

Chicago 10, Illinois

Specialists in design and manufacture of miniature tungsten filament incandescent lamps; miniature glass enclosed switches; heating units; electronic devices and rare gas tubes.

RANGE—LAMPS MANUFACTURED

1 to 60 volts

0.05 to 1.0 amperes

1 to 200 lumens

Bulb specifications may incorporate colors, natural or dipped: ruby, green, amber, opal, et cetera, and particular shape desired. Size: standard miniature sizes or to desired specification.

BULB SIZES:

Tubular — 0.070″ to 0.750″ diameter

Spherical— 0.25 to 1.00″ diameter

BASE SPECIFICATIONS

Either standard miniature: candelabra, auto, miniature or midget screw and bayonet, or special size bases using standard threads 2-56 and larger.

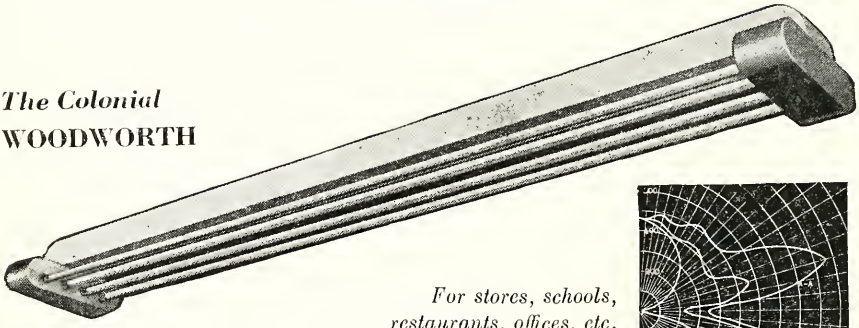
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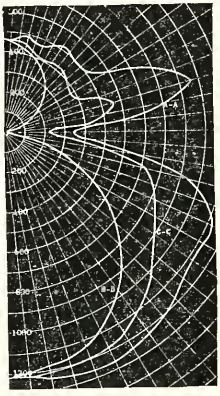
A complete line of standard automobile, radio, flashlight, surgical, aircraft and scientific instrument lamps is manufactured.

COLONIAL Lighting

Manufactured by
COLONIAL ELECTRIC PRODUCTS, INC.
Paterson 4, New Jersey

The Colonial WOODWORTH



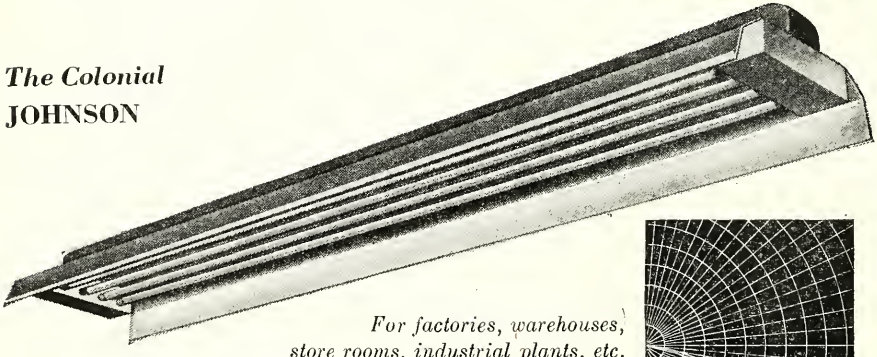


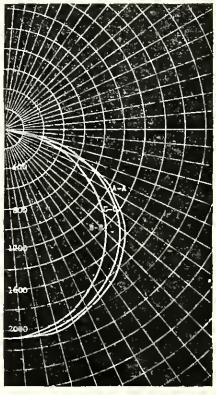
For stores, schools, restaurants, offices, etc.

Specifications

Length 6 or 8 ft.-width 12½″ (4 lamp) 6½″ high
Weight approximately 46 lbs. (4 lamps). Baked enamel finish—two tone combinations. For stem suspension or flush ceiling mounted 2-4-6-8-10 lamp combination—
Individual or continuous
Enclosed transformers 750 or 900 volts
90% efficient

The Colonial JOHNSON





For factories, warehouses, store rooms, industrial plants, etc.

Specifications

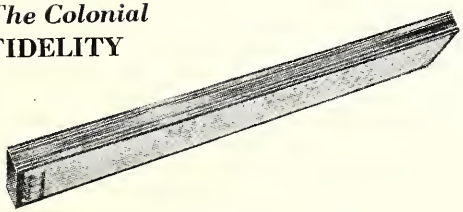
Length 6 or 8 ft.-width 18″-height 7½″ (4 lamp)
Weight approximately 54 lbs. Baked enamel finish, white inside, gray outside
Stem or chain suspension—Individual or continuous
Available in 2 or 4 lamps.
Enclosed transformers 750 or 900 volts.
Efficiency 79.5%
Fixtures shown are stock items—special and custom built upon request—coves, valances, strip, decorative and other designs made with accuracy to fit.
See your local distributor, or contact home office.

Illumination Data from tests by Electrical Testing Laboratories Inc.

COLONIAL *Lighting*

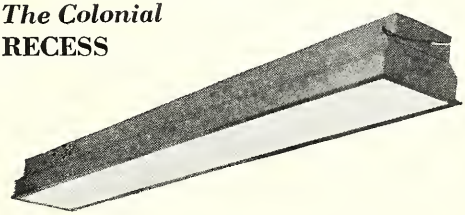
Manufactured by
COLONIAL ELECTRIC PRODUCTS, INC.
Paterson 4, New Jersey

The Colonial
FIDELITY



Specifications
Aluminum sides, louvred bottom
6 or 8 ft. long, 15″ wide, 8″ high
4 lamps—750 or 900 volts
Stem mounted
Individual or continuous
Distribution curves on request
Aluminum and baked enamel finish

The Colonial
RECESS



Specifications
Glass louvred or open bottom
Individual or continuous
6 or 8 ft. long-11$\frac{7}{8}$″ wide-8$\frac{1}{8}$″ high
2 or 4 lamps—900 volts only
Distribution curves on request.

COLONIAL

COLD CATHODE FEATURES.

Instant start—no starters required, 43 lumens per watt, Underwriters approved fixtures. Disconnect switch opens primary circuit when cover of housing box is removed. Patented* red disc covers hole when lamp is out of socket. *Pending.
Transformers enclosed in metal wireway
20 and 25 MM lamps, standard lengths. Lamps wired independently in multiple
Lamps and transformers guaranteed one year, Baked enamel finishes
Our laboratory and field reports indicate 10,000 hours average life
150° c. electrode temperature by our Lab test
No moving parts.
Quality workmanship.

LAMP COLORS

White
Warm white
Soft white
Daylight
Blue
Pink
Old rose
Gold

Numerous architects, Engineers, Lighting authorities and manufacturers report entirely satisfactory installations with long efficient lamp life and low maintenance.

COLONIAL-PREMIER COMPANY

466 W. Superior St., Chicago, Illinois

PHONE: SUPERIOR 0351

MANUFACTURERS:

CERTIFIED LAMPS AND SHADES

PORTABLE LAMPS WALLETTES DESK LAMPS



CERTIFIED LAMP

Circline lamp in combination with 100-200-300 watt incandescent used in mogul socket.

The Circline has precision three-point suspension placed correctly in the shade to spread maximum area of light without glare.

Wired for fast starting and permits clear radio reception. Ten feet of rubber covered cord from base to plug.

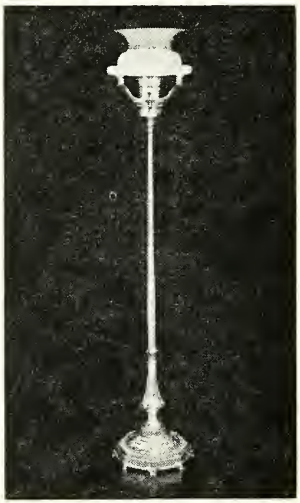
All parts machined for accurate alignment.

Bases and shafts pressure die cast of zinc alloy.

Triple-grit polished, buffed, plated and covered with polymerin, then oven-baked to insure long-lasting finish.

All lamps meet Underwriters Laboratories specifications. Standards set up by Electrical Testing Laboratories are adhered to rigidly, and Illuminating Engineering Society recommendations are followed.

Shade dimensions conform to Certified Lamp Specifications. All linings white for good diffusion. Frames are cadmium-plated so shades can be washed repeatedly without a trace of rust. Entire shade, including decorative trim, is sewn.



WALLETTES

Wallette, an adjustable lamp, suitable for bed, sewing machine, dressing table, desk, chairs and studio couches.

The Wallette has a braided cord running through a curved arm. The arm brings the lighting element away from the wall so that the light falls over the shoulder of the user reducing shadows and specular reflection.

The cord is inserted into a precision-balanced counterweight which maintains the lighting element and shade in any position desired by the reader. The user can adjust the shade height into any position by just raising or lowering the cord without changing position.



Raising the shades widens the area of light and lowering it increases the foot candle reading on the printed page. A diffusion bowl reduces glare and increases general illumination in the room for more comfortable seeing.

All parts are triple-grit polished and plated, then covered with polymerin and oven-baked to insure long-lasting beauty of finish.

Each shade has white lining for good light diffusion from its ten inch diameter. Each frame is cadmium plated and all shades are sewn so that they may be washed repeatedly.

An eight foot rubber covered cord extends from the counterweight and may be plugged into the wall in any standard outlet.

COMPCO CORPORATION

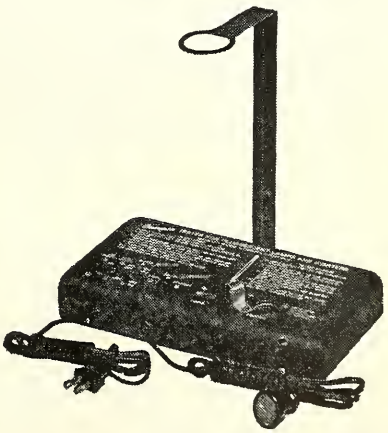
2251 West St. Paul Ave.

Chicago 47, Illinois

Manufacturers of Commercial, Industrial and Residential Fluorescent Fixtures

FLUORESCENT LAMP AND STARTER TESTERS. A compact, easy-to-operate instrument for checking all standard size fluorescent lamps and starters. Tests accurately at the flip of a switch. Tests 14 watt—15″ length; 15 watt—18″ length; 20 watt—24″ length; 30 watt—36″ length; 40 watt—48″ length fluorescent lamps. Guide post and ring holds lamp snugly in vertical testing position. Indicator lamp protected with hooded guard. Instrument panel carries complete, step-by-step instructions for testing of lamps and starters. For 60-cycle, 110-125 volt alternating current only.

TESTS STARTERS—Starter socket on the same instrument board enables testing of FS-2 for 14, 15, 20 watt lamps and FS-4 for 30 and 40 watt lamps; also new "No-Blink" starters. Unit is completely self-contained—has one cord with male plug for current outlet connection and one cord with female plug for attaching to lamp to be tested.



Model No. 2c114—Complete as illustrated. 5½″ x 11½″—shipping weight 5 lbs. each. Individually boxed. Packed 10 per shipping carton. Approximate shipping weight 45 lbs.

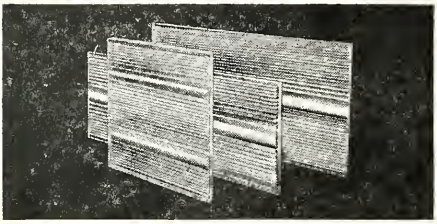
CORNING GLASS WORKS

Corning, New York

Engineered Lightingware

ALBA-LITE and MONA-LITE LIGHTINGWARE . . . new rolled sheet forms of opal glass. ALBA-LITE is a light opal glass (high transmission and low reflection), while MONA-LITE is a dense opal glass (high reflection and low transmission). Transmission is approximately 64% to 69% for ALBA-LITE and 30% to 35% for flat MONA-LITE $\frac{1}{8}$" glass.



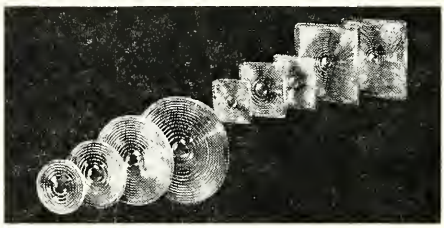


LENS PANELS

are Fresnel-type lenses for line light sources. One to four rows of lamps may be used and beam spreads up to 90° and fixture efficiences up to 64% may be attained. Lens panels are available in lengths up to 60", and accommodate the regular and slimline fluorescent lamps.

LENSLITES

are Fresnel-type lenses for filament sources. Beam spreads up to 72° and concentrations to 8.5° may be obtained by the use of general service lamps at various lamp positions. All Lenslites are made of a PYREX brand heat-resisting glass and will accommodate up to 1000 watt lamps.





LIGHTING BOWLS

are pressed crystal glass ware decorated with fired-in ceramic enamel colors. In lens-bottom dining room bowls a Fresnel-type lens is pressed integrally in the bottom of the bowl (risers in gold). These concentrate a light beam onto the table while the balance of the room is evenly lighted.

ENCLOSING GLOBES, REFLECTORS & SHADES

Enclosing globes are of Monax brand dense opal glass for general diffuse lighting and Galax brand semi-indirect lighting. Fixture efficiencies up to 85% in Monax brand glass and 87% in Galax brand glass are attainable. Pressed reflectors (I.E.S. type) and shades are of opal (Monax brand) glass.



Note: Corning Glass Works does not manufacture or sell lighting fixtures.

Corning Lighting Engineers will gladly work with you on your lighting glassware requirements.

"CORNING", "MONAX" and "GALAX" are registered trademarks of Corning Glass Works, Corning, New York.

All Illumination Data from test by Company Laboratory.

CROUSE-HINDS COMPANY

Syracuse 1, N. Y.

Offices: Birmingham — Boston — Buffalo — Chicago — Cincinnati — Cleveland — Dallas — Denver — Detroit Houston — Indianapolis — Kansas City — Los Angeles — Milwaukee — Minneapolis — New York Philadelphia — Pittsburgh — Portland, Ore. — San Francisco — Seattle — St. Louis Washington. *Resident Representatives:* Albany — Atlanta — Charlotte New Orleans — Richmond, Va.
CROUSE-HINDS COMPANY OF CANADA, LTD.,
Main Office and Plant: TORONTO, ONT.

Floodlights

A complete line of light-duty sheet aluminum and heavy-duty cast aluminum floodlights from 100 watts to 2000 watts, explosion-proof floodlights 200 watts and 500 watts, special units for pits, tunnels, underpasses, viaducts, underwater swimming pool lighting, etc. See data below and Floodlight Catalog 316.

Searchlights

Searchlights for hand control, pilot house control, and remote control, sizes 8″, 12″, 18″, 24″ and 36″; also, 12″ signalling searchlights. See Floodlight Catalog 316, section 205.

Airport Lighting Equipment

A complete line of lighting equipment for small and large airports including rotating and flashing beacons, runway marker lights, taxi lights, obstruction lights, wind indicating devices, traffic control equipment, control desks and panels, ceiling projectors, ceilometer. See Airport Catalog 317.

Explosion-proof Industrial Lighting Equipment

Explosion-proof fixtures with and without porcelain enamel and high bay aluminum reflectors, sizes 60 watts, 100 watts, 150 watts, 200 watts, 300 watts and 500 watts for Class I, Groups C and D, hazardous locations. See Condulet Catalog 2500, section 85.

Dust-Tight Industrial Lighting Equipment

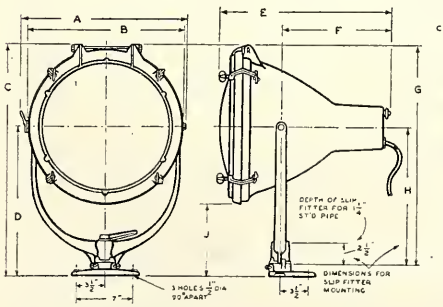
Dust-tight fixtures with and without reflectors, sizes 100 watts, 200 watts, 500 watts for Class II, Groups E, F and G, and Class III, hazardous locations. See Condulet Catalog 2500, section 85.

Vaportight Industrial Lighting Equipment

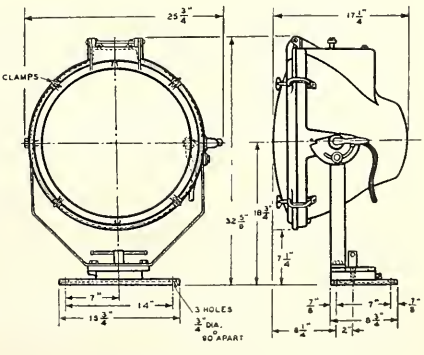
Fixtures with and without reflectors, sizes 100 watts, 150 watts, 200 watts, 500 watts. See Condulet Catalog 2500, section 25.

Heavy Duty Cast Aluminum Floodlights

Type	A	B	C	D	E	F	G	H	J
ADE-14	18⅝″	16¾″	25 1/16″	16¾″	17⅜″	11¼″	24 3/16″	15½″	8⅜″
ADE-16	20⅛″	19¼″	28¾″	18⅝″	21″	13⅜″	27¼″	17⅛″	9″



Dimensions—Types ADE-14 and ADE-16
500 and 1000-Watt



Dimensions—Type LCE-1120
1500-Watt

CROUSE-HINDS COMPANY

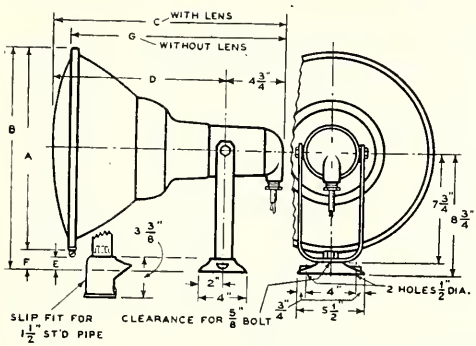
FLOODLIGHT ILLUMINATION DATA*
TYPES ADE-12, ADE-14, ADE-16, LCE-1120 FLOODLIGHTS

TYPE	Cat. No.	Lens	Lamp Watts	Lamp Bulb	Beam Lumens	Beam C. P.	Beam Spread Hor.	Beam Spread Vert.
ADE-12	42428A	Plain	200	PS-30	1586	7952	44.0°	43.0°
ADE-12	42428A	50° Spread	200	PS-30	1566	5638	55.0°	47.0°
ADE-12	42428A	100° Spread	200	PS-30	1680	1859	140.0°	64.0°
ADE-12	42428A	Diffusing	200	PS-30	1898	2490	96.0°	91.0°
ADE-12	42429A	Plain	200	PS-30	1402	13525	32.0°	31.0°
ADE-12	42429A	50° Spread	200	PS-30	1394	9900	44.0°	30.0°
ADE-12	42429A	100° Spread	200	PS-30	1482	2840	125.0°	36.0°
ADE-12	42429A	Diffusing	200	PS-30	1688	4308	68.0°	69.0°
ADE-12	42429A	Plain	250	G-30	1476	61525	14.6°	13.5°
ADE-12	42429A	50° Spread	250	G-30	1456	25789	31.7°	14.0°
ADE-12	42429A	100° Spread	250	G-30	1636	7566	116.0°	15.0°
ADE-14	42740	Plain	500	PS-40	5066	16048	54.0°	52.0°
ADE-14	42740	50° Spread	500	PS-40	5068	15680	64.0°	45.0°
ADE-14	42740	100° Spread	500	PS-40	5290	5253	148.0°	48.5°
ADE-14	42740	Diffusing	500	PS-40	5904	7289	99.0°	96.0°
ADE-14	42739	Plain	500	PS-40	3548	67991	25.0°	21.5°
ADE-14	42739	50° Spread	500	PS-40	3922	35583	42.6°	26.0°
ADE-14	42739	100° Spread	500	PS-40	4168	9105	130.0°	34.0°
ADE-14	42739	Diffusing	500	PS-40	4724	12693	67.0°	64.0°
ADE-14	42921A	Plain	500	G-40	2794	209402	12.0°	14.0°
ADE-14	42921A	50° Spread	500	G-40	3388	62521	32.0°	16.5°
ADE-14	42921A	100° Spread	500	G-40	3836	15389	122.0°	20.0°
ADE-16	42741	Plain	1000	PS-52	8796	51925	44.0°	43.0°
ADE-16	42741	50° Spread	1000	PS-52	9494	35524	62.0°	43.0°
ADE-16	42741	Diffusing	1000	PS-52	11168	13918	90.0°	99.0°
ADE-16	42741	100° Spread	1000	PS-52	10356	12610	128.0°	46.5°
ADE-16	42932	Plain	1000	PS-52	7212	204305	18.8°	19.5°
ADE-16	42932	50° Spread	1000	PS-52	7674	96450	37.0°	20.0°
ADE-16	42932	Diffusing	1000	PS-52	9188	28958	56.0°	56.5°
ADE-16	42932	100° Spread	1000	PS-52	9156	29751	122.0°	23.4°
ADE-16	42743	Plain	1000	G-40	7326	591267	10.4°	11.3°
ADE-16	42743	50° Spread	1000	G-40	7306	149628	34.0°	12.6°
ADE-16	42743	100° Spread	1000	G-40	7722	36531	120.0°	12.5°
LCE-1120	42745	Plain	1500	PS-52	14178	112352	42.0°	34.0°
LCE-1120	42745	50° Spread	1500	PS-52	14400	77520	59.5°	32.5°
LCE-1120	42745	Diffusing	1500	PS-52	15788	26574	84.0°	78.0°
LCE-1120	42953	Plain	1500	PS-52	13048	284793	22.5°	18.7°
LCE-1120	42953	50° Spread	1500	PS-52	13330	146869	43.2°	21.0°
LCE-1120	42953	Diffusing	1500	PS-52	15742	34872	74.0°	69.0°
LCE-1120	42746	Plain	1500	G-48	11042	741099	14.0°	11.6°
LCE-1120	42746	50° Spread	1500	G-48	11446	209100	35.0°	14.0°

* This information is approximate and is given for estimating purposes only. If more detailed information is needed, apply to the Illumination Department of the Crouse-Hinds Company, Syracuse, N. Y.

CROUSE-HINDS COMPANY

Types MDB-14 and MDB-16 Floodlights



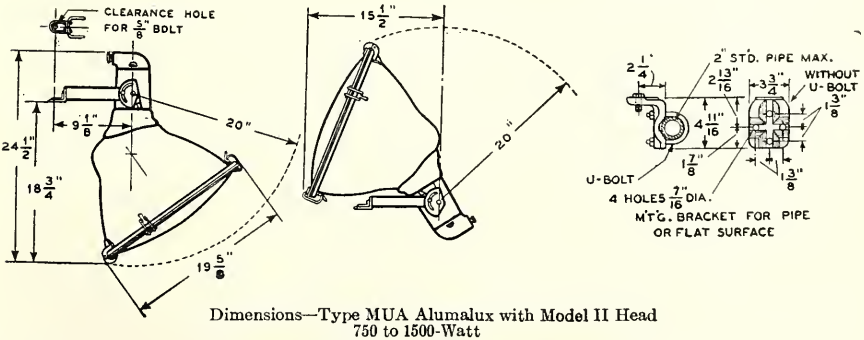
	MDB-14	MDB-16
A	14 1/2"	16 3/4"
B	15 5/8"	17 1/4"
C	16 1/2"	19 3/4"
D	12"	14 3/8"
E	1/4"	3/8"
F	1 5/8"	3/4"
G	15 3/8"	18"

Dimensions—Types MDB-14 and MDB-16
500 and 1000-Watt

Floodlight Illumination Data*

Type	Reflector	Lens	Lamp		Beam		Beam Spread	
			Watts	Bulb	Lumens	C.P.	Hor.	Ver.
MDB-14	Wide Beam	Plain	500	PS-40	5268	4504	106.0°	106.0°
	Medium Beam	Plain			3828	14000	65.0°	66.0°
	Narrow Beam	Plain			3254	55331	24.0°	24.5°
	Narrow Beam	50° Spread			3596	25960	43.0°	31.0°
	Narrow Beam	100° Spread			4342	8107	131.0°	47.0°
	Narrow Beam	Diffusing			4544	11600	79.0°	82.5°
MDB-16	Wide Beam	Plain	1000	PS-52	10038	7584	111.0°	109.0°
	Medium Beam	Plain			8368	24580	77.0°	72.0°
	Narrow Beam	Plain			7634	165570	21.0°	20.5°
	Narrow Beam	50° Spread			7544	86200	39.0°	21.0°
	Narrow Beam	100° Spread			9108	26550	124.0°	32.0°
	Narrow Beam	Diffusing			9270	26810	66.0°	61.0°

Type MUA Alumalux Floodlight



Dimensions—Type MUA Alumalux with Model II Head
750 to 1500-Watt

*FLOODLIGHT ILLUMINATION DATA**

Floodlight			Lamp		Beam		Beam Spread	
Type	Refl.	Lens	Watts	Bulb	Lumens	C.P.	Hor.	Ver.
MUA	W.B.	Plain	1500	PS-52	17648	23283	98.0°	93.0°
	N.B.	Plain	1500	PS-52	14994	168471	31.0°	29.0°
	N.B.	Stippled	1500	PS-52	17780	46349	66.8°	64.4°

* This information is approximate and is given for estimating purposes only. If more detailed information is needed apply to the Illumination Department of the Crouse-Hinds Company, Syracuse, N. Y.

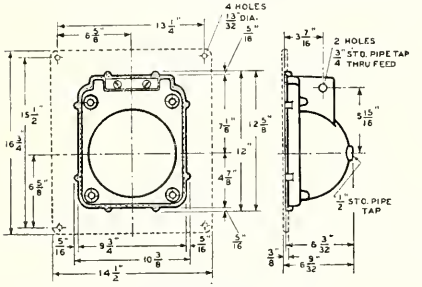
Pit and Tunnel Lights

Pit Lights

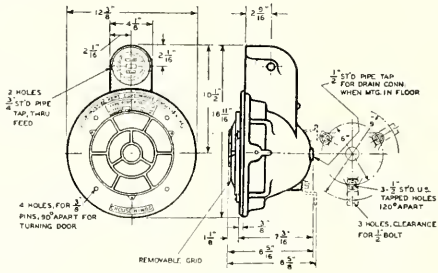
The drawings below show dimensions of type RCD-8 vaportight and weatherproof lighting unit for mounting on the surface or flush in concrete for lighting of underpasses, tunnels, wash racks, and pits where non-explosion-proof equipment is permissible. Type RCD-8 is also available in a model designed for mounting in the floor. Standard spacing for pits is 12 feet staggered, 200 watts each. Wash racks two rows, one 7 to 8 feet high and one near the floor, both on 4 to 6-foot centers.

Type RCDE-8

Explosion-proof for hazardous areas. Can be set flush in concrete or on surface. Also available with floodlight mounting.



Dimensions—Type RCD-8
100 to 200-Watt



Dimensions—Type RCDE-8
100 to 200-Watt

Underwater Swimming Pool Floodlighting

Type SPS

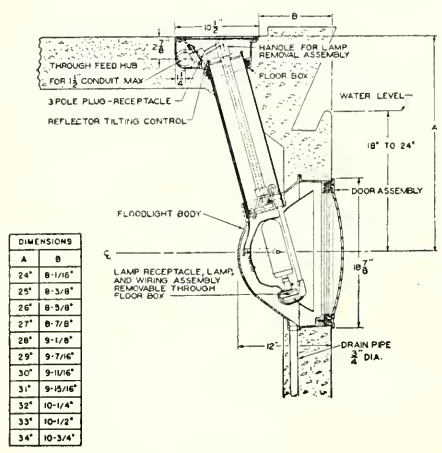
Dry niche for installation in manholes or passageways with 1000-watt or 500-watt, G-40 bulb lamps.

Type RPS

Equivalent to wet niche except for provision for relamping from walkway. Uses 1000-watt, T-20 bulb, mogul bipost base, 115-volt lamp.

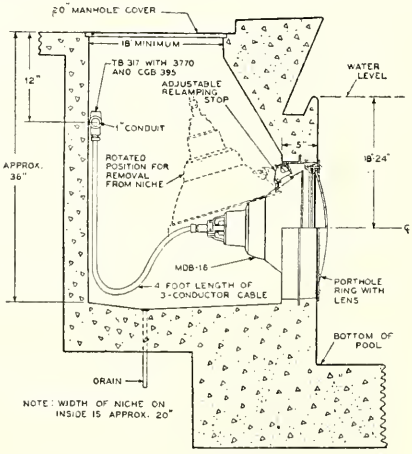
Installation

Install 1.5 to 3 watts per square foot for outdoor pools, 3 to 5 watts for indoor pools. Maximum spacing, deep end 12 feet, shallow end 15 feet. Mount center of unit 18 to 24″ below water level.



DIMENSIONS	
A	B
24"	8-1/16"
25"	8-3/8"
26"	8-3/8"
27"	8-7/8"
28"	9-1/8"
29"	9-7/16"
30"	9-11/16"
31"	9-15/16"
32"	10-1/4"
33"	10-1/2"
34"	10-3/4"

Dimensions—Type RPS
1000-Watt

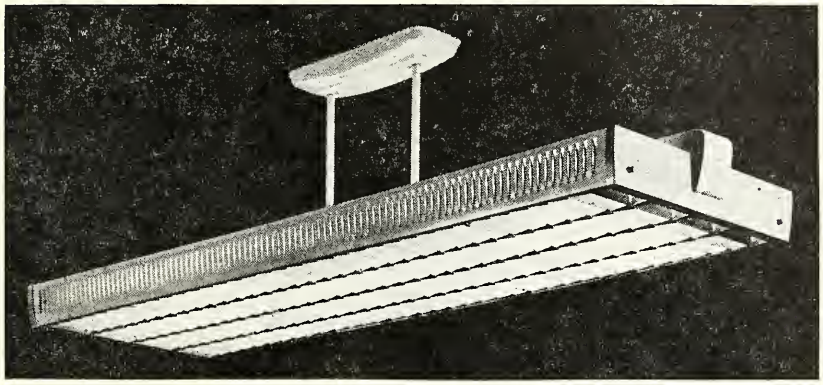


Installation Details—Type SPS in Manhole
1000-Watt

CURTIS LIGHTING, INC.

6135 W. 65th Street, Chicago 38, Illinois

CURTIS "*Anniversary*" LUMINAIRES



"ANNIVERSARY" LUMINAIRE INDIVIDUAL UNIT—CATALOG NO. 51—C

For four 40-watt lamps per section. Recommended for both store and office lighting, the "Anniversary" Luminaire can be used either as an individual unit or in continuous runs. It is an all-metal unit with a very shallow body of 3 inches. Side panels are designed so that lamps are louvered and reflected light is utilized to illuminate and create a decorative pattern.

The "Anniversary" Luminaire is of the general diffusing type with the top completely open for better utilization of the indirect component. The direct component is shielded 30° lengthwise and crosswise by the attractive one piece louver.

Material and Finish: Made of Steel with reflecting surfaces and louver finished white "Fluracite". End plates and hanger finished light gray.

Installation and Maintenance: Curtis hangers permit simplified installation. Lamps and starters can be changed from above without opening the louver. Louver is hinged on both sides and is easily removed.

Dimensions: Width, 18″; overall depth, 4½″; depth of body, 3″; length, incl. end ornament, 51⅜″. Standard suspension is 12″, but stems for 18″, 21″, 36″ and 48″ suspensions are carried in stock. Net weight is 33 lbs.

REPORT

Electrical Testing Laboratories, Inc.

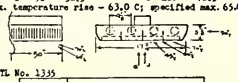
3 EAST END AVENUE AT 79TH STREET, NEW YORK 21, N. Y.

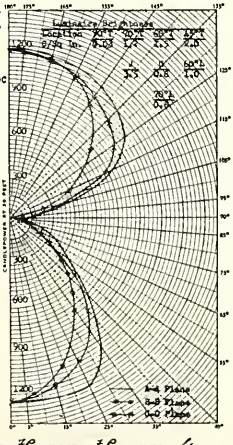
Report No. 321047 Order No. 14674-L Plate No. 53831 Date July 2, 1947

CANDLEPOWER DISTRIBUTION
CAT. NO. 51 FOUR-40-WATT SUSPENSION-MOUNTED FLUORESCENT LUMINAIRE*
Type - General Diffuse
Tested under Fleur-O-lier Specifications
Rendered to Curtis Lighting, Inc.

Lamps - Four - 40 Watts; 118 Volts; 2300 Lumens; T-12 White Fluorescent.
Unit - Synthetic enamelled metal housing, reflection factor 0.86; synthetic enamelled aggerate louvers, side panels vertically slotted.
Test - Candlepower distribution in three vertical planes intersecting in the center of the unit; A-A normal, B-B parallel and C-C 45° to the tubes.

Light output in per cent of bare lamps
0°- 60° - 26.4 90°-180° - 46.0
0°- 90° - 32.3 0°-180° - 78.3
Max. temperature rise - 63.0 C; specified max. 65.0C





*ETL No. 1335

Angles	CANDLEPOWER Plane A-A	Plane B-B	Plane C-C
180°	1190	1170	1150
175°	1180	1170	1150
165°	1150	1140	1120
155°	1120	1070	1090
145°	1109	965	1010
135°	1050	820	925
125°	965	650	840
115°	780	451	725
105°	420	240	368
95°	140	55	161
90°	78	7.1	84.3
85°	77	42.5	87
75°	187	112	152
65°	349	202	239
55°	465	355	416
45°	755	570	685
35°	1090	780	970
25°	1290	980	1110
15°	1280	1150	1210
5°	1280	1260	1270
0°	1280	1280	1280

TESTED BY [illegible] PLOTTED BY FP COMPUTED BY FP CHECKED BY [illegible]

REPORT APPROVED BY William Stuttle ENGINEER PHOTOMETRIC DEPARTMENT

Caroline E. Horn IN CHARGE OF TEST

NOTE: This report is the property of the client. Its publication in full or in part is not authorized. Laboratory reports and the use of the laboratory name for the purpose of publicity are prohibited by R.S.A. Revised 1946 Supplement.

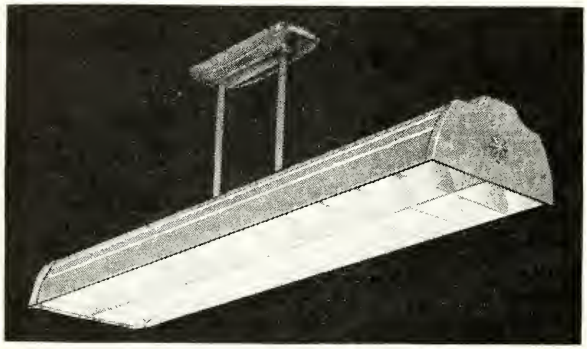
COEFFICIENTS OF UTILIZATION
"ANNIVERSARY" LUMINAIRE
CATALOG NO. 51

REFLECTION FACTOR	CEILING	75%			50%			30%	
	WALLS	50%	30%	10%	50%	30%	10%	30%	10%
ROOM INDEX	J	.26	.22	.21	.22	.20	.19	.18	.17
	I	.32	.28	.27	.28	.25	.23	.22	.21
	H	.35	.32	.30	.30	.28	.27	.25	.23
	G	.39	.36	.33	.34	.31	.29	.27	.26
	F	.42	.38	.35	.35	.33	.31	.29	.27
	E	.45	.42	.39	.39	.36	.34	.31	.30
	D	.49	.45	.43	.41	.39	.37	.33	.32
	C	.51	.48	.45	.43	.40	.39	.34	.33
	B	.54	.51	.49	.45	.43	.41	.36	.35
	A	.56	.53	.51	.47	.44	.43	.38	.36

For average conditions a maintenance factor of 75% is suggested.

CURTIS LIGHTING, INC.

CURTIS "*Forty-Sixty*" LUMINAIRES



FOUR-FOOT
Units for two 40-watt lamps.

FIVE-FOOT
Units for two 100-watt lamps.

The "Forty-Sixty" is designed for eye comfort. The low brightness of the luminaire blends with the illuminated ceiling, producing a comfortable field of vision. High levels of illumination without distracting and harmful glare are readily attained with this luminaire.

Finish: Satin Aluminum. Alzak Aluminum reflectors and louver fins. White "Fluracite" wiring channel and end plates. Ornamental star in Ivorytone.

REPORT
Electrical Testing Laboratories, Inc.
2 EAST END AVENUE AT 79th STREET, NEW YORK 21, N. Y.

Report No. 319977 Order No. 14015-L Plate No. 53571 Date April 7, 1947

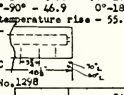
CANDLEPOWER DISTRIBUTION

CAT. NO. 4060-C TWO-40-WATT SUSPENSION-MOUNTED FLUORESCENT UNITS WITH LOUVERS

TESTED IN ACCORDANCE WITH SPECIFICATIONS FOR FLUORESCENT LUMINAIRES - TYPE - SEMI-DIRECT

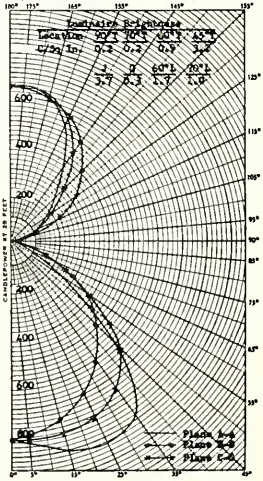
Rendered to Curtis Lighting, Inc.

Lamps - Two - 40 Watts; 120 Volts; 2300 Lumens; T-12 White Fluorescent.
Unit - Synthetic enamel channel, reflection factor 0.86; sides and cross louvers Alzak aluminum.
Test - Candlepower distribution in three vertical planes intersecting in the center of the unit; A-A normal, B-B parallel and C-C 45° to the tubes.
Light output in per cent of bare lamps -
0°-60° - 42.0 90°-180° - 32.2
0°-90° - 46.9 0°-180° - 79.1
Max. temperature rise - 55.0 C; specified max. 55.0 C



*ETL No. 1298

Angles	CANDLEPOWER Plane A-A	Plane B-B	Plane C-C
180°	650	640	645
175°	650	635	640
165°	625	615	620
155°	525	570	560
145°	372	500	446
135°	252	418	300
125°	198	322	191
115°	124	219	128
105°	68	113	68.5
95°	31.5	24.5	26
90°	22	6.5	16
85°	23.5	21	19
75°	35	93.5	48
65°	69	217	148
55°	251	368	390
45°	600	499	630
35°	885	610	745
25°	930	700	815
15°	905	770	830
5°	840	820	830
0°	830	830	830



TESTED BY [illegible] PLOTTED BY [illegible] COMPUTED BY [illegible] CHECKED BY [illegible]
REPORT APPROVED BY [illegible] ENGINEER, PHOTOMETRIC DEPARTMENT
IN CHARGE OF TEST [illegible]

NOTE: This report is the property of the client. Its interpretation is subject to the accuracy and representative character of the samples and to the information given to the tests from which it is derived. This report may not be reproduced except in full, without written approval.

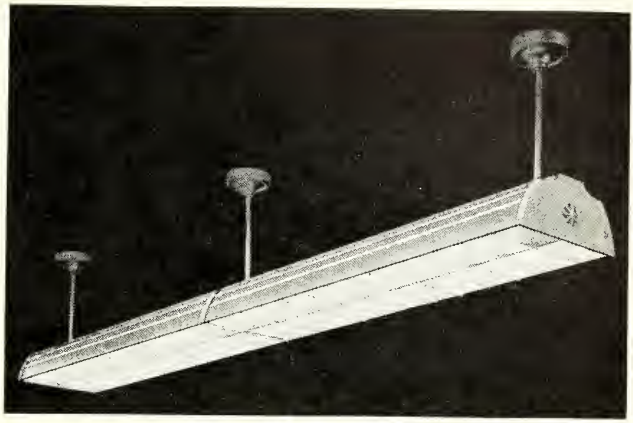
CATALOG NO. 4060-C
Dimensions: Width, $12\frac{1}{2}$″; depth of body, $5\frac{1}{2}$″; length, $48\frac{3}{4}$″, including ornaments; stem hanger suspension 12″ ceiling to top of body. Weight installed, approximately 25 lbs.
Continuous Luminaires: 4060-C can be used in continuous runs with two-stem hangers. Connectors are included. For continuous runs with single-stem hangers see next page.

CATALOG NO. 4061-C
Dimensions: $60\frac{3}{4}$″ long. Weight installed, approximately 33 lbs.

Light Control: The ceiling is illuminated by an indirect component of 40% of the light output The 60% direct component is louvered to provide 35° crosswise and 25° lengthwise shielding. Less than 5% of the bare lamp output is in the 60°–90° zone.

CURTIS LIGHTING, INC.

for OFFICE, SCHOOLS, DRAFTING ROOMS, ETC.



Continuous Luminaires: For continuous fixtures with single-stem hangers, one Basic Unit is used with as many Extension Sections as necessary to complete run.

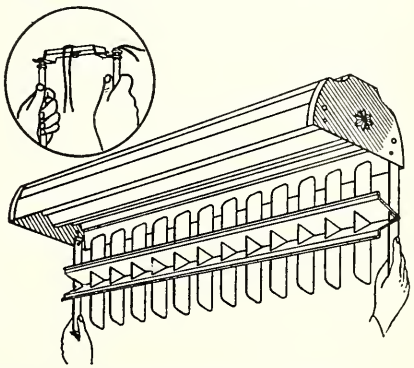
Illumination Data: Coeficients of Utilization calculated from E.T.L. photometric curve are given below for the "Forty-Sixty" unit only. If "Forty-Sixty-ONE" is to be used decrease coefficients by approximately 10%.

Construction: Louver is hinged and will swing down for cleaning and relamping or for access to the wiring channel. All metal with no horizontal surfaces to collect dust. Simplified hanger design permits easy installation. Stems are carried in stock for 18″, 24″, 36″ and 48″ suspension.

COEFFICIENTS OF UTILIZATION
"FORTY-SIXTY" LUMINAIRE

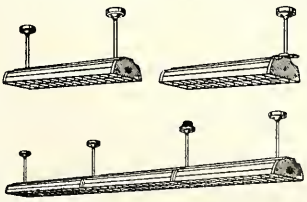
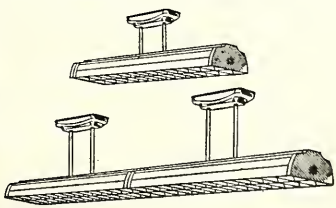
REFLECTION FACTOR	CEILING	75%			50%			30%	
	WALLS	50%	30%	10%	50%	30%	10%	30%	10%
ROOM INDEX	J	.32	.28	.27	.29	.27	.25	.26	.23
	I	.37	.36	.34	.36	.33	.32	.31	.29
	H	.43	.40	.38	.39	.36	.35	.34	.33
	G	.46	.44	.42	.42	.40	.38	.37	.36
	F	.49	.47	.44	.44	.42	.40	.39	.38
	E	.53	.51	.48	.48	.45	.44	.42	.40
	D	.57	.53	.51	.50	.48	.47	.44	.43
	C	.59	.56	.53	.52	.50	.48	.45	.44
	B	.61	.58	.56	.54	.52	.51	.47	.46
	A	.63	.60	.58	.56	.54	.52	.48	.47

For average conditions a maintenance factor of 75% is suggested.



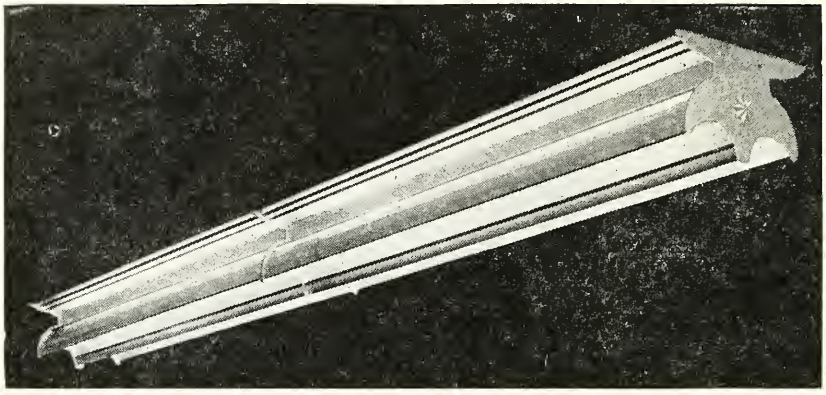
CATALOG NUMBERS FOR INDIVIDUAL AND EXTENSION UNITS

Wired: With high power factor two-lamp ballast for 110–125 volt AC circuits and FS-4 or FS-64 starters. Less lamps. Bears Underwriters' Label. Catalog numbers are for complete units carton packed with standard 12″ suspension.

WATTS	SINGLE-STEM HANGER		TWO-STEM HANGER	
	Basic Unit	Extension Section	Individual Unit or Extension	Stem Spacing
2– 40	4060-CB	4060-CE	4060-C	7½″
2–100	4061-CB	4061-CE	4061-C	21″
				

CURTIS LIGHTING, INC.

CURTIS "*Low Brightness*" SKYLUX



Two-Section "Low Brightness" Twin SkyLux Unit

"*Low Brightness*" SkyLux for two 40-watt lamps per section, Catalog No. 980-C. Recommended for both store and office lighting. Primarily for ceiling mounting as individual four-foot units or in continuous runs. Hangers are available for pendant mounting.

"Low Brightness" SkyLux is characterized by high utilization and low luminaire brightness. It is pleasingly luminous when lighted, the Alzak Aluminum reflecting surfaces having a soft silvery appearance.

The side reflectors shield the lamps in the zone from 60° to 90°. There are no horizontal reflecting or diffusing surfaces to collect dust. Maintenance costs are low.

ELECTRICAL TESTING LABORATORIES, INC.
New York, N. Y.

REPORT NO. 315923 ORDER NO. 10912-L PLATE NO. 52772

CANDLEPOWER DISTRIBUTION

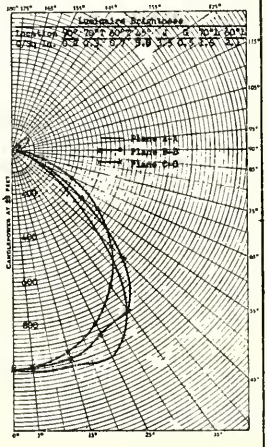
CAT. NO. 980-C TWO-40-WATT SUSPENSION-MOUNTED FLUORESCENT LUMINAIRE
Tested in accordance with Specifications for Fluorescent Luminaires - Type - Direct
Rendered to Curtis Lighting, Inc.

Lamps - Two - 40 Watts; 118 Volts; 2100 Lumens; T-12 White Fluorescent.
Unit - Alzak aluminum reflectors and sides, reflection factor 0.82; specified min. 0.75; suspension mounted.
Test - Candlepower distribution in three vertical planes intersecting in the center of the unit; A-A normal, B-B parallel and C-C 45° to the tubes.
Light output in per cent of bare lamps
0°- 60° - 51.5
0°- 90° - 58.5
90°-180° - 4.5
0°-180° - 63
Maximum temperature rise - 54.0 C; specified max. 55.0 C.



*ETL No.1087

Angles	CANDLEPOWER Plane A-A	Plane B-B	Plane C-C
155°		0	
145°	0	5.5	0
135°	75	7	6
125°	92	7.5	54.5
115°	76	8.5	60.5
105°	51.5	8.5	39.5
95°	43	4.5	29
90°	37.5	2.5	24.5
85°	43	25.0	29.5
75°	59	148	57
65°	110	298	153
55°	450	465	375
45°	540	640	695
35°	885	760	890
25°	1040	870	920
15°	1020	950	985
5°	1010	995	995
0°	1000	1000	1000



Report Approved by
William Plank
Engineer, Photometric Department.

Caroline E. Horn
In Charge of Test.

Tested by: [illegible] Plotted by: [illegible] Computed by: AP Checked by: [illegible] April 2, 1945.

Material and Finish: Made of Alzak Aluminum and steel, with Satin Aluminum finish.

Dimensions: Overall height, $6\frac{7}{8}$"; width, $11\frac{1}{2}$"; length, $48\frac{11}{16}$". Extra sections add $48\frac{3}{16}$".

Illumination Data: The Coefficients of Utilization Chart given below is derived from the E.T.L. photometric curve shown at left.

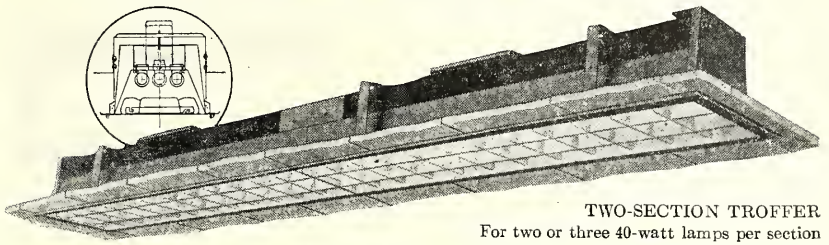
COEFFICIENTS OF UTILIZATION
"LOW BRIGHTNESS" SKYLUX LUMINAIRE
CATALOG NO. 980 C

REFLECTION FACTOR	CEILING	75%			50%			30%	
	WALLS	50%	30%	10%	50%	30%	10%	30%	10%
ROOM INDEX	J	.33	.30	.28	.31	.30	.28	.30	.27
	I	.39	.37	.36	.38	.36	.35	.36	.34
	H	.42	.41	.40	.41	.40	.39	.39	.38
	G	.45	.44	.43	.44	.43	.41	.42	.41
	F	.48	.46	.45	.46	.45	.43	.45	.43
	E	.51	.49	.47	.49	.48	.46	.47	.45
	D	.54	.51	.50	.52	.50	.49	.49	.48
	C	.55	.53	.51	.53	.51	.50	.50	.49
	B	.56	.54	.53	.54	.52	.51	.51	.50
	A	.57	.55	.54	.55	.54	.52	.52	.51

For average conditions a maintenance factor of 75% is suggested.

CURTIS LIGHTING, INC.

CURTIS FLUORESCENT RECESSED TROFFERS



TWO-SECTION TROFFER
For two or three 40-watt lamps per section

These troffers are of three general types. They are equipped with side and end flanges and are easy to install in any type ceiling.

Alzak Aluminum Troffers—Louvered, 1712-C series (two-lamp); and 1713-C series (three-lamp).

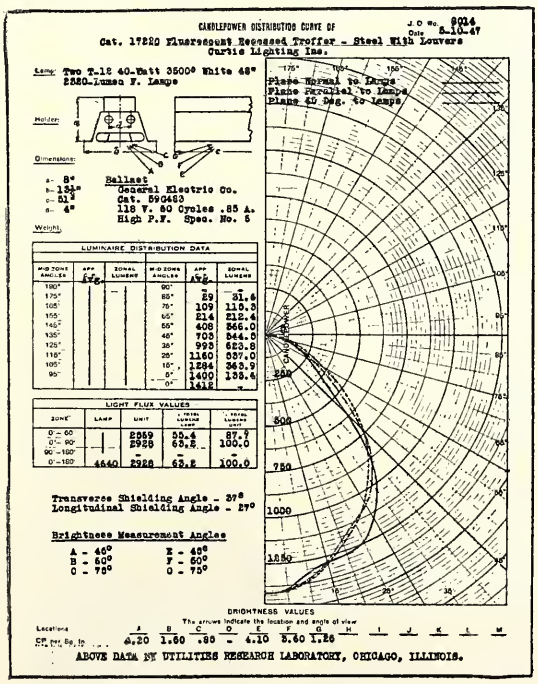
Louvers minimize crosswise luminaire brightness at normal viewing angles. These units have Alzak Aluminum reflectors and louvers; wire-ways, etc., are of heavy gauge steel.

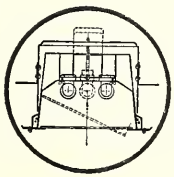
"Fluracite" Finish Steel Troffers—Louvered, 1722-C series (two-lamp); and 1723-C series (three-lamp).

These troffers have white "Fluracite" finish reflectors and louvers; brightness is sufficiently low for many applications. Louvered troffers require minimum maintenance.

Glass Panel Troffers—1752-C series (two-lamp); and 1753-C series (three-lamp). Glass panels in these troffers are arranged so that one will slide over the other for easy maintenance. These troffers are preferred for some jobs from an appearance standpoint. Brightness is moderate both crosswise and lengthwise.

Illumination Data: The Coefficients of Utilization Chart shown is calculated from the curve and is for the two-lamp "Fluracite" Finish Louvered Troffer. Coefficients of Utilization for the Alzak Aluminum Troffers and Glass Panel Troffers can be approximated by deducting 10% from the figures shown. With all types it is preferable to install the Troffers crosswise of the normal direction of vision, in which case the brightness of Alzak Troffers is 40% less than the "Fluracite" type at normal viewing angles.





COEFFICIENTS OF UTILIZATION
2-LAMP RECESSED TROFFER (FLURACITE)
CATALOG NO. 1739-C

REFLECTION FACTOR	CEILING	75%			50%			30%	
	WALLS	50%	30%	10%	50%	30%	10%	30%	10%
ROOM INDEX	J	.35	.32	.31	.34	.32	.31	.32	.30
	I	.42	.40	.39	.41	.40	.39	.39	.38
	H	.45	.44	.43	.44	.43	.42	.43	.41
	G	.48	.47	.46	.47	.46	.45	.46	.44
	F	.51	.49	.48	.49	.48	.47	.48	.47
	E	.53	.52	.51	.52	.51	.50	.50	.49
	D	.56	.54	.53	.55	.54	.52	.53	.52
	C	.58	.56	.55	.56	.55	.54	.54	.53
	B	.59	.57	.56	.57	.56	.55	.55	.54
	A	.60	.59	.58	.58	.57	.56	.56	.55

For average conditions a maintenance factor of 75% is suggested.

CURTIS LIGHTING, INC.

FLUORESCENT CURTISTRIP. *Wired units.*

Individual one-lamp units or continuous strip lighting. Fluorescent CurtiStrip is applicable to a variety of commercial and industrial lighting tasks. Supplied in lengths as required (multiples of two feet only). Channel made of steel with decorative end ornaments and finished Satin Silvertone.

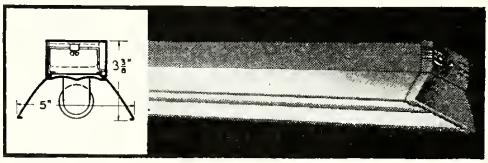
Not listed here, but also available, are units with steel reflectors finished in white "Fluracite". Both the aluminum and steel reflector units are available in an economy type with plain rust resistant channel without the decorative reflector ends and with plain channel ends.

Applications: Deep Reflector Type units are used for general lighting or for local lighting over counters, work tables, etc; Shallow Reflector units for local lighting or inverted for indirect lighting; Asymmetric Reflector units for vertical or sloping surfaces, shelves, displays, cases, coves, etc; Reflectorless Type units, Catalog No. 956-C, (not illustrated—Economy Type), are used in coves, cases, niches, signs, etc.

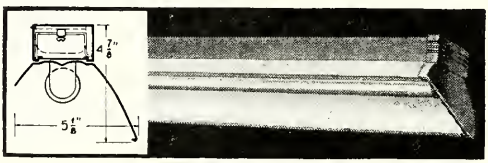
Illumination Data: Coefficients of Utilization computed from the E.T.L. photometric curve shown below are for the Deep Symmetric type unit with Alzak Reflectors. Coefficients of Utilization and brightnesses for "Fluracite" reflectors are slightly *higher*.



Illustrated above is Deep Reflector Type: Catalog No. 973-C with Semi-Concentrating Alzak Aluminum Reflectors.



Shallow Reflector Type: Catalog No. 975-C with distributing Alzak Aluminum Reflectors.



Asymmetric Reflector Type: Catalog No. 977-C with Alzak Aluminum Reflectors.

COEFFICIENTS OF UTILIZATION
DEEP REFLECTOR (ALZAK ALUMINUM)

REFLECTION FACTOR	CEILING	75%			50%			30%	
	WALLS	50%	30%	10%	50%	30%	10%	30%	10%
ROOM INDEX	J	.42	.39	.37	.41	.39	.37	.38	.36
	I	.51	.48	.47	.49	.47	.46	.47	.45
	H	.54	.53	.52	.53	.52	.51	.52	.50
	G	.58	.57	.56	.57	.56	.54	.55	.54
	F	.61	.60	.58	.60	.59	.57	.58	.56
	E	.64	.63	.61	.63	.62	.60	.61	.59
	D	.68	.65	.64	.66	.65	.63	.64	.63
	C	.70	.68	.66	.68	.66	.65	.65	.64
	B	.71	.69	.68	.69	.68	.67	.66	.65
	A	.72	.70	.69	.70	.69	.68	.68	.66

For average conditions a maintenance factor of 75% is suggested.

REPORT
Electrical Testing Laboratories, Inc.
2 EAST END AVENUE AT 79TH STREET, NEW YORK 21, N. Y.

Report No. 320397 Order No. 13974-L Plate No. 53717 Date May 13, 1947

CANDLEPOWER DISTRIBUTION

CAT. NO. 974C-4 SUSPENSION-MOUNTED #105 DEEP SYMMETRIC ALZAC ALUMINUM REFLECTOR*

Rendered to Curtis Lighting, Inc.

Lamps - One - 40 Watt; 118 Volts; 2300 Lumens; T-12 White Fluorescent.
Unit - No.105 Deep Symmetric Alzac aluminum reflector.
Test - Candlepower distribution in three vertical planes intersecting in the center of the unit; A-A normal, B-B parallel and C-C 45° to the tubes.

Light output in per cent of bare lamps
0°- 60° - 68.3
0°- 90° - 75.8
90°-180° - 0
0°-180° - 75.8

*ETL No. 1282

Angles	CANDLEPOWER Plane A-A	Plane B-B	Plane C-C
90°	0	0	0
85°	7	31	8
75°	7	125	33
65°	13	236	83
55°	142	357	259
45°	345	491	458
35°	570	605	620
25°	730	700	715
15°	785	770	775
5°	805	805	805
0°	810	810	810

TESTED BY JW PLOTTED BY Sc COMPUTED BY Sc CHECKED BY CB

REPORT APPROVED BY William Frank PHOTOMETRIC DEPARTMENT

Carlos E. Torres IN CHARGE OF TEST

CURTIS LIGHTING, INC.

INCANDESCENT RECESSED LIGHTING

Deep type recessing units bear Underwriters' Recessing Label and are fitted with "X-Ray" Silver Mirror Reflectors for high efficiency. Shallow types have an aluminum interior finish and two sockets arranged to hold lamps in a horizontal position. Shallow types, and unhoused types (illustrated at bottom of page), do not carry Underwriters' Label. All units are fitted with hinged rim which holds the louvers and lens.

Maximum allowable spacing is approximately $1\frac{1}{2}$ times distance of unit to working plane for good distribution of light with distributing type units. Concentrating reflector units provide a spotlight effect immediately under the unit. The diameter of the area covered is approximately one-third of the mounting height.

METAL HOUSED RECESSING UNITS

Large Round Deep Units—For 300-watt medium base lamps. $15\frac{1}{4}''$ required for recessing. Dimensions: Housing, $14\frac{1}{2}''$ dia.; rim, $17\frac{3}{8}''$ overall. Available for 500-watts with louver only.

Large Round Shallow Units—For two 150-watt lamps. 6″ required for recessing. Dimensions: Housing, $14\frac{1}{2}''$ dia.; rim, $17\frac{3}{8}''$ overall.

Small Round Deep Units—For 200- or 300-watt medium base lamp. $12\frac{1}{2}''$ required for recessing. Dimensions: Housing, $11\frac{3}{16}''$ dia.; rim, $12\frac{5}{8}''$ overall.

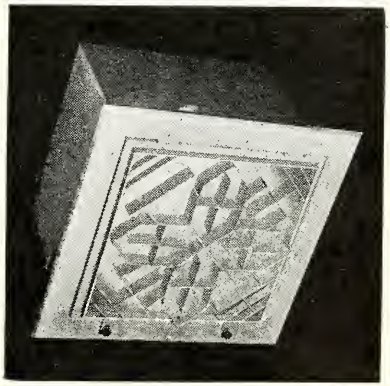
Small Round Shallow Units—For two 100-watt lamps. 6″ required for recessing. Dimensions: Housing, $11\frac{3}{16}''$ dia.; rim, $12\frac{5}{8}''$ overall.

Square Deep Units—For 200- or 300-watt medium base lamp. $13\frac{1}{4}''$ required for recessing. Dimensions: Housing, $10\frac{7}{8}''$ square; rim, $13\frac{1}{4}''$ square.

Square Shallow Units—For two 100-watt lamps. 6″ required for recessing. Dimensions: Housing, $10\frac{7}{8}''$ square; rim, $13\frac{1}{4}''$ square.

All of the above can be had with diffusing glass lens alone, louver alone or with glass lens and louver. Pattern louvers are used with square units, concentric louvers with round units. Two type reflectors (concentrating and distributing) are available in the "deep" units.

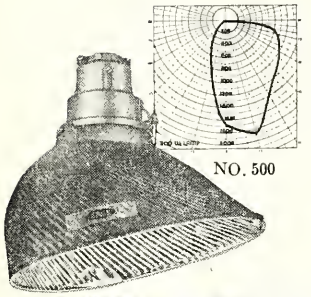




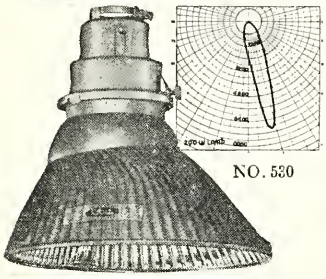


CURTIS LIGHTING, INC.

"X-Ray" SHOW WINDOW REFLECTORS



NO. 500



NO. 530

"X-Ray" Show Window Reflectors are made of crystal glass mirrored with pure silver and protected from deterioration by the "Golden Armor" backing.

Use Nos. 420 or 530 for shallow windows, No. 500 for deep windows; for large windows or for super lighting, No. 1010.

These reflectors can be installed on CurtiStrip Wiring Channel or may be recessed on finishing flanges.

No. 420—Reflector for 150- or 100-watt lamp. Louver, extra accessory, is No. 12420 (U-Type). Dimensions: Diameter, $8\frac{5}{8}$". Height with Holder, $7\frac{9}{16}$".

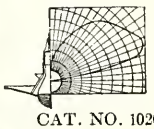
No. 500—Reflector for 300-, 200- or 150-watt medium base incandescent lamp. Dimensions: Width, 10"; depth, front to back, $10\frac{1}{2}$". Height with Holder, 10".

No. 530—Reflector for 300-, 200- or 150-watt medium base incandescent lamp. Louver, extra accessory, is No. 12531 (U-Type). Dimensions: Diameter, $9\frac{3}{4}$". Height with Holder, $9\frac{1}{16}$".

No. 1010—Reflector for 500- or 300-watt mogul base incandescent lamp. Dimensions: Diameter, 13". Height with Holder and socket, $12\frac{3}{8}$".

CURTIS "Eye-Comfort" LUMINAIRES

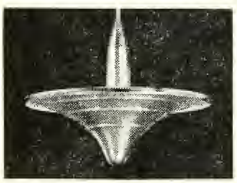


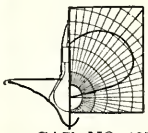


CAT. NO. 1020

"Discus" Luminaires—For Silvered bowl lamps, low priced and efficient.

Catalog No. 1020—For 300- or 500-watt lamp. Bowl diameter 20". Suspension to top of bowl, 36". Finish: Alzak Aluminum. Also available for 750- or 1000-watt lamps, Cat. No. 1024.



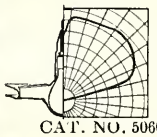


CAT. NO. 1250

"Edge-Ray" Luminaires—The "Edge-Ray" ring at the top of the bowl redirects a portion of light to give a luminous effect.

Catalog No. 1250—For 300- or 500-watt lamp. Bowl diameter $21\frac{1}{2}$". Suspension to top of bowl, 36". Finish: Alzak Aluminum. Also available for 750- to 1500-watt lamps Cat. No. 1270.



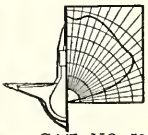


CAT. NO. 5060

"Larra" Luminaires—Beauty in shining aluminum and softly luminous glass.

Catalog No. 5060—For 300- or 500-watt lamp. Bowl diameter 20". Suspension to top of bowl, 36". Finish: Alzak Aluminum. Also available for 750- to 1500-watt lamps, Cat. No. 5080.





CAT. NO. 5090

"Winner" Luminaire—High efficiency is provided by the "X-Ray" Silver Mirror Reflector concealed in the bowl.

Catalog No. 5090—For 300- or 500-watt lamp. Bowl diameter $19\frac{1}{2}$". Suspension to top of bowl, 36". Finish: Satin Gray.

Deena PRODUCTS COMPANY

Lamp Manufacturers

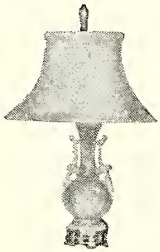
825 S. Wabash Ave., Chicago 5, Illinois

SHOWROOMS

Chicago: American Furniture Mart
Los Angeles: Los Angeles Furniture Mart
San Francisco: Western Merchandise Mart
High Point, N. Carolina: High Point Furniture Mart
Dallas, Texas: 1303½, Elm Street



Three Primary Features of Deena Lamps:



1. Visual Comfort
2. Durability
3. Decorative Styling

FLOOR LAMPS

Deena Floor Lamps are furnished in a choice of 3-way or 6-way lighting. Lamps are electroplated in our own plating division and equipped with hand-sewn rayon shades made in our modern Chicago plant.

TABLE LAMPS

Deena Vitrified China Table Lamps are individually designed and cast in our Paducah, Kentucky plant. Modern tunnel kilns, under supervision of our ceramic engineers, produce a lustrous and durable product. Our vitrified china is hand-decorated by artists trained especially for this work. 22 K gold is used in decorating and it is kiln-fired to insure a quality finish. Shades are designed to match.

CONSTRUCTION

Deena Lamps are mechanically constructed to withstand any damage that may be encountered during average home use. Concealed reinforcing has been incorporated into most designs to provide added protection to the internal connections and electrical wiring.



SHADES

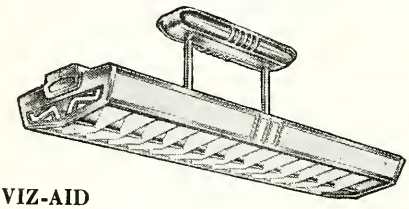
Rayon shades are hand-sewed and permanently fastened at strategic points on the frame. All wire frames are designed to hold the material under moderate stress. This assures retention of the desired shape over a long period of years.

Member of the Certified Lamp Manufacturers

DAY-BRITE LIGHTING, INC.

5411 Bulwer Ave. St. Louis 7, Mo.

Engineers, Designers, Manufacturers of Fluorescent Lighting Equipment



VIZ-AID

Suspension Type Unit

Lamps—Single units and single sections of continuous runs available for two 40-watt and two 100-watt fluorescent lamps.

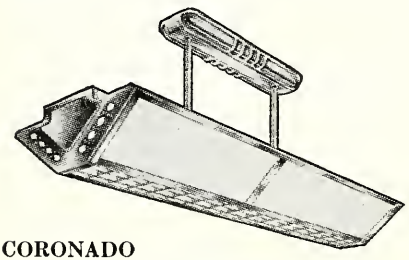
Mounting—Surface type units mounted direct to ceiling. Continuous fixtures attached to pre-installed mounting straps. Suspension type units supported by twin stem hanger assembly. Continuous fixtures supported by adjustable single stem hangers at section coupling points and ends.

Dimensions—40-watt fixture body is 13″ wide by $6\frac{1}{4}$″ deep by $48\frac{1}{2}$″ long. 100-watt fixture body is $16\frac{1}{4}$″ wide by 8″ deep by $60\frac{1}{4}$″ long. Single unit hangers measure 27″ from ceiling to top of fixture. Adjustable hangers for continuous runs provide $1\frac{1}{4}$″ adjustment to $28\frac{1}{2}$″ maximum length.

Construction—Chassis of die-formed steel, press-welded together and finished in baked white enamel. Removable wireway cover snaps into position. Enclosures are of press-welded construction of die-formed steel parts. Center V-shaped louver is of specular Alzak with lateral louvers of steel finished in baked white enamel. Enclosure frame is finished in baked lustre aluminum enamel with side panels of ribbed diffuse glass. All hangers are supplied with swivel fittings and hanger assemblies are finished in baked lustre aluminum enamel. Single stem hangers for continuous installations have hand-operated fittings providing over one-inch of vertical adjustment.

Servicing—The enclosures are held in position on the chassis by two spring tension clips and can be removed and replaced without the use of tools. Service chains support the enclosures when they are released from the chassis for cleaning. Chains can be unhooked for complete removal of enclosures if desired.

Wiring—All fixtures are wired and include NO-BLINK type starters and High Power-Factor ballasts for 110-volt, 60-cycle, A.C. operation.



CORONADO

Suspension Type Unit

Lamps—Single units accomodate four 40-watt fluorescent lamps.

Mounting—Surface type units mounted direct to ceiling. Suspension type units supported by twin stem hanger assembly.

Dimensions—Body is 15″ wide by 7″ deep by $48\frac{3}{4}$″ long. Hangers measure 27″ from ceiling to top of fixture.

Construction—Chassis of die-formed steel, press-welded together and finished in baked white enamel. Enclosures are of press-welded construction of die-formed steel parts. Egg-crate type louvers are finished in baked white enamel. Enclosure frames are finished in baked lustre aluminum enamel with side panels of ribbed diffuse glass. All hangers are supplied with swivel fittings and hanger assemblies are finished in baked lustre aluminum enamel.

Servicing—The enclosures are held in position on the chassis by two spring tension clips and can be removed and replaced without the use of tools. Service chains support the enclosures when they are released from chassis for cleaning. Chains can be unhooked for complete removal of enclosure if desired.

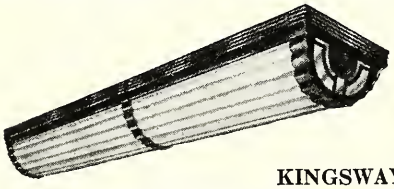
Wiring—All fixtures are wired and include NO-BLINK type starters and High Power-Factor ballasts for 110-volt, 60-cycle, A.C. operation.

All Illumination data from tests by Electrical Testing Laboratories Inc. except for data on Coronado unit which is from Company Laboratory.

DAY-BRITE LIGHTING, INC.

5411 Bulwer Ave. **St. Louis 7, Mo.**

Engineers, Designers, Manufacturers T.M. Reg. U.S. Pat. Off. of Fluorescent Lighting Equipment



KINGSWAY
Surface Mounted Single Unit

Lamps—Single units and single and multiple sections for continuous runs are available for two and three rows of 20-watt and 40-watt fluorescent lamps.

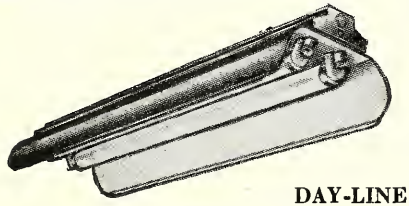
Mounting—Surface mounted direct to ceiling. Continuous sections for 8-ft., 4-ft., and 2-ft. lengths are provided with couplings and ends.

Dimensions—All fixtures are 11½″ wide by 7¼″ deep and are 2½″ longer than end-to-end total of the lamp lengths.

Construction—Back plate and side rail assembly is of die-formed steel construction, finished in baked lustre aluminum enamel with die-formed steel intermediate straps finished to match. Die-cast ends are satin finish. Interior reflectors which act as wireway covers are finished in baked white enamel. Flutted glass cylinders are provided in 24″ lengths. They have a high transmission factor and are sufficiently opaque to minimize glare and conceal interior parts.

Servicing—Glass cylinders are removed by sliding toward either end and lifting out. Straps and ends remain in position.

Wiring—All fixtures are wired and include NO-BLINK type starters and High Power-Factor ballasts for 110-volt, 60-cycle, A.C. operation.



DAY-LINE
Single Industrial Unit

Lamps—Single units and single and multiple sections for continuous runs are available for two and three rows of 40-watt lamps and two rows of 100-watt lamps.

Mounting—Can be suspended by means of chain, pipe, rod, or messenger cable. Also mounted direct through back of channel. Patented "Ice-tone" Hanger Clamps provide flexible means of support with pipe or rod hangers.

Dimensions—Two and three-lamp 40-watt units 52¾″ long, 13¼″ wide, 8⅛″ high. Two-lamp 100-watt units 66″ long, 16¼″ wide, 8⅛″ high. Continuous sections in multiples of these lengths for single and double lamp lengths.

Construction—Chassis of units and channel of continuous sections is identical in construction and size. It is designed to accommodate hanger fittings and provide increased strength. Arrangements are made for simple conversion of units to continuous fixtures if required. Open-end reflectors are of steel, finished in vitreous porcelain enamel.

Servicing—Sockets, lamp starters, and ballasts are fastened in channel, leaving reflector free for complete removal for servicing and cleaning operation.
The reflector is supported by two captive wing-nuts having a 2″ diameter bearing surface. On and off operation requires less than a minute and no tools are needed. The lamp starters are located behind the sockets and are easily replaced without disturbing the lamps.

Wiring—All fixtures are wired and include NO-BLINK type starters and High Power-Factor ballasts for 110-volt, 60-cycle, A.C. operation.

PERFORMANCE DATA

FIXTURE	DAY-LINE Industrial			KINGSWAY Surface		VIZ-AID Suspended		CORONADO Suspended
FOR LAMPS	2-40	3-40	2-100	2-40	3-40	2-40	2-100	4-40
OVERALL EFFICIENCY	79%	72%	71%	60%	62.5%	74.5%	71%	70.3%
Max. C. P. Norm. to Lamp	1070	1640	2100	530	810	920	1610	995
UTILIZATION—Rm. Index "A", Ceiling 75%, Walls 50%	.74	.69	.69	.47	.51	.57	.52	.53

EAST SIDE METAL SPINNING & STAMPING CORP.

Est. 1892

Linden N.J.

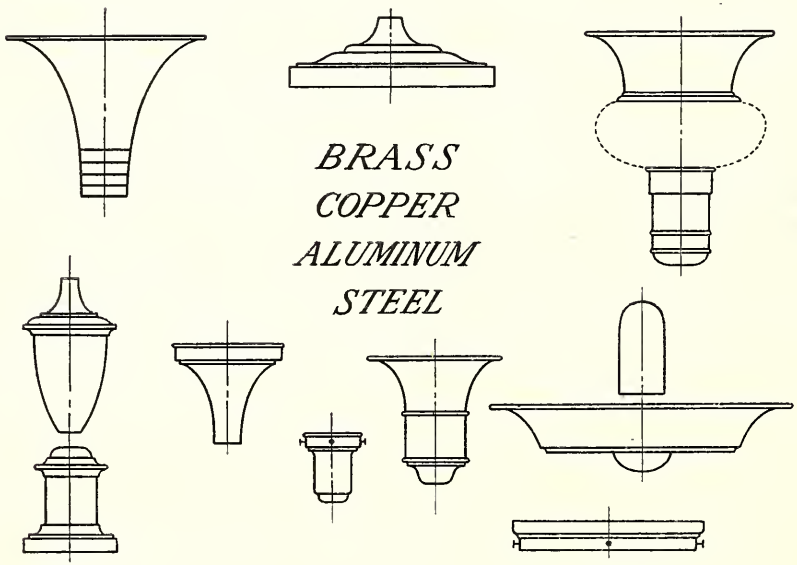
Manufacturers

of

SHEET METAL PARTS

to the

ILLUMINATING INDUSTRIES



Deep Drawings up to 10½″

Spinnings—Stampings—Dies—Jigs

M-40

E. I. du Pont de Nemours & Co., (Inc.)

Finishes Division **Wilmington 98, Delaware**



BRANCH OFFICES

ATLANTA
619 Peachtree Street, N.E.

BOSTON
1019 Commonwealth Avenue

CHICAGO
2100 Elston Avenue

CLEVELAND
Union Commerce Building

DALLAS
2812 Gaston Avenue

PHILADELPHIA
1616 Walnut Street

SAN FRANCISCO
235 Second Street

"COLOR CONDITIONING" AND BRIGHTNESS ENGINEERING

The properly engineered illumination and the scientific painting of any given area, whether it be office, schoolroom, retail establishment or industrial plant are finely interwoven—each is largely dependent upon the other for proper results.

Paint colors should reflect light to the area where it is needed, in a form that will be acceptable to the human eye, in "seeing light" rather than glare—this is the hypothesis on which the Du Pont "Color Conditioning" program is based.

"Color Conditioning" is the result of research carried out over a period of years in collaboration with Mr. Arthur A. Brainerd,* Philadelphia Electric Company, and Mr. Faber Birren, color consultant. It begins at the machine. The traditional light-absorbing Dark Tool Gray has been replaced by a middle-shade tone on the body of the machine and a "spotlight" color in the lighter range around the actual working area. As a result, light at the point of focal concentration is measurably increased.

This phase of Color Conditioning, called "Three Dimensional Seeing", centers about three colors that are basic wherever proper seeing conditions are desired in machine operations. The colors, illustrated by chips, are Horizon Gray, Spotlight Buff and Spotlight Green. Horizon Gray is a neutral Color, with sufficiently high light reflection to allow the body of the machine to contribute to good utilization of light in the plant. Spotlight Buff was selected as a satisfactory contrast in color and brightness between ferrous metals being worked on the machine and the background of the working area. Spotlight Green was likewise selected for use where brass, leather and similarly colored objects were being worked. Both "spotlight" colors are high in light reflection and hence afford better light at the working point.

Properly painting machines does not completely solve the illumination-painting problem in industry, however. It has been found that color—scientifically selected and tested color—must be extended throughout the plant to place illumination upon its highest efficiency plane. Ceilings should be painted white, in order to properly

* IES Report #9, "Salvaging Waste Light for Victory", by Arthur A. Brainerd & Robert A. Massey; IES Report #16, "Improved Vision in Machine Tool Operations by Color Contrast", by Arthur A. Brainerd & Matt. Denning.

E. I. du Pont de Nemours & Co., (Inc.)
Finishes Division Wilmington 98, Delaware

DUPONT
REG. U.S. PAT. OFF.

A TYPICAL "COLOR CONDITIONING" COMBINATION

CEILING—painted white, to properly direct light downward, into the critical seeing area.

SIDEWALL—finished in DuPont "Color Conditioning" #7 Light Green Semi-Gloss; high degree of light reflection without the accompanying glare and distraction associated with white walls; provides an area of visual relaxation from critical seeing tasks; maintains the proper degree of brightness necessary to correct brightness engineering.

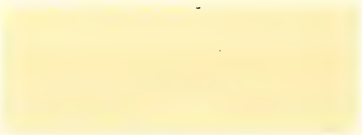
DADO—DuPont "Color Conditioning" #8 Medium Green Gloss; used as a means of promoting cleanliness in industrial areas and maintaining the correct brightness ratio to the upper wall color.



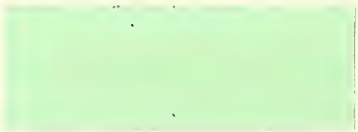
"THREE DIMENSIONAL SEEING" COLORS FOR MACHINERY



HORIZON GRAY



SPOTLIGHT BUFF



SPOTLIGHT GREEN

direct light downward toward the critical seeing area; soft, light colors—blue, green, ivory, sunlight or gray on upper walls provide an area of visual relaxation and maintain the proper balance of brightness engineering. Dados, being below the level of necessary high light reflection and within the area where maintenance becomes the most pressing problem, are painted in darker values of the upper wall color, or of complimentary colors.

Plants where "Color Conditioning" recommendations have been followed report a marked increase in the overall light reflectance and a raising of the co-efficient of light utilization.

Not only does scientific painting increase lighting efficiency, it increases the efficiency of the eye as well, by achieving correct brightness engineering and hence contributing to a more uniform seeing condition. It is this aspect of "Color Conditioning" that extends it far beyond the industrial plant, where it first came into being. For proper brightness engineering and uniform seeing conditions are desirable in any area where good seeing is a factor.

The principles of "Color Conditioning" have been successfully applied to offices, schools, stores and other commercial institutions catering directly to the public in the sales and service field.

The "Color Conditioning" system of painting is based upon known factors of paint color values and their correct application to specific areas and specific lighting problems. Personal color preferences have no part in "Color Conditioning."

DuPont has felt it best to recommend that, for proper results, each "Color Conditioning" installation be the result of a survey by a trained DuPont color engineer, and not the outcome of selection from a color card. The use of end-wall treatments to take advantage of a special lighting situation, the degree of gloss advisable in any one area and to maintain the preferred brightness ratio of 1 to 5 or 1 to 10 (the maximum allowable), and similar problems, call for individual, specialized surveys. A letter to the nearest branch office will be sufficient to secure advisory services on "Color Conditioning" in connection with any illuminating engineering project.

LIGHTING AND COLOR

Certain colors are affected by various types of artificial illumination. Incandescent light will slightly gray all blues; fluorescent lighting may tend to make blue appear a bit stark and vivid; mercury vapor light is best used with green, gray or white, as yellow appears gaudy, blue becomes unduly luminous and distracting and all warm tones, ivory, peach and rose turn muddy under its rays. However, "Color Conditioning" colors, excepting in these few instances, may be used satisfactorily in connection with any type of illumination.

ELECTRICAL TESTING LABORATORIES, INC.

HELPFUL SERVICES

applying to each chapter of the

IES LIGHTING HANDBOOK

REFERENCE DIVISION

1. PHYSICS OF LIGHT PRODUCTION—Radiometric Tests
2. LIGHT AND VISION—Glare and Diffusion Tests, Effect of Flicker
3. STANDARDS, NOMENCLATURE, ABBREVIATIONS and SYMBOLS—Assistance to Committees
4. COLOR—Spectrophotometric Tests
5. MEASUREMENT OF LIGHT—Photometry and Illumination Tests, Illuminometer Calibration, Standards of Candlepower, Lumens and Color Temperature
6. LIGHT SOURCES—Incandescent and Fluorescent Units Tests, Rating and Life Test-Incandescent, Fluorescent, Discharge Lamps
7. LIGHT CONTROL—Reflecting Globes, Shades, Mirror Tests, Candlepower Distribution and Brightness Tests
8. LIGHTING CALCULATIONS—Distribution Data, Illumination Surveys, etc., Coefficient of Utilization

APPLICATION DIVISION

9. DAYLIGHTING—Measurement—Outdoor and Indoor
10. INTERIOR LIGHTING—Illumination Surveys, Certification of Lighting Equipment (See Opposite Page)
11. EXTERIOR LIGHTING—Street and Airport Measurements
12. SPORTS LIGHTING—Distribution, Light and Glare, Lighting Surveys
13. TRANSPORTATION LIGHTING—Automotive Lighting, Area Lighting, Car Lighting Tests
14. PHOTOGRAPHIC, REPRODUCTION, PROJECTION AND TELEVISION LIGHTING—Repeating Flash Projection, Photo Flashlight, Filter Transmission and Flood-Lighting Equipment Tests
15. MINIATURE LAMP APPLICATIONS—Christmas Tree Lighting, Flashlights
16. MISCELLANEOUS APPLICATIONS OF RADIANT ENERGY—Reflectance, Absorption, Diffusion of Surfaces, Paints and Finishes

2 East End Avenue at 79th Street, NEW YORK 21, N. Y.

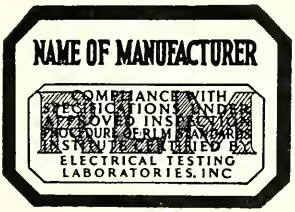
CERTIFICATION INSIGNIA OF E.T.L.



Label for Certified Lamp Makers



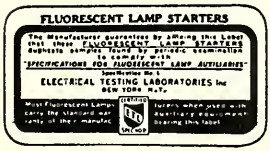
Label for Residence Fixtures



Label for RLM Industrial Fixtures



Label for Fluorescent Ballasts



Label for Fluorescent Starters

Label for Fleur-O-Lier Fixtures



Using above labels, the number of manufacturers having testing and certification contracts with ETL are:

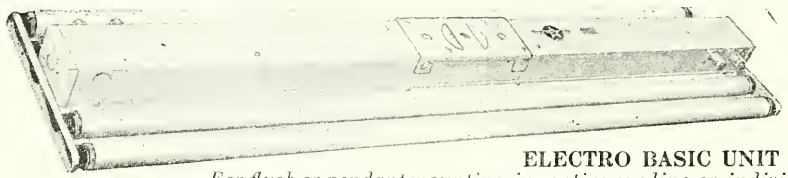
RLM STANDARDS INSTITUTE **13**	FLEUR-O-LIER MANUFACTURERS **27**	CERTIFIED LAMP MAKERS **102**
AMERICAN HOME LIGHTING INSTITUTE *(Under development)*	CERTIFIED BALLAST MANUFACTURERS **7**	CERTIFIED STARTER MANUFACTURERS **10**

ELECTRO MANUFACTURING CORPORATION

2000 W. FULTON ST., CHICAGO, ILL.

COMMERCIAL LUMINAIRES

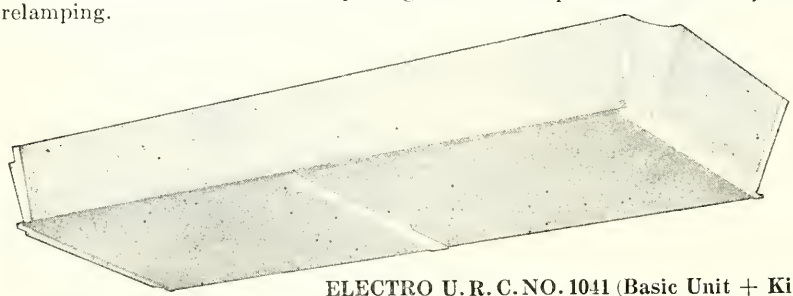




ELECTRO BASIC UNIT ✕ 1040

For flush or pendant mounting in continuous line or individually.

Can be converted instantly into any type of commercial 4-light 40 watt luminaire with aid of accessories from packaged kits. Lamps inserted from top for simple relamping.



ELECTRO U. R. C. NO. 1041 (Basic Unit + Kit No. 1)

A standard 4-light, 40-watt luminaire. Specially treated glass sides and ends. Skytex ribbed glass bottom panels. Transmitted light is efficiently diffused. Glass easily removed for cleaning.



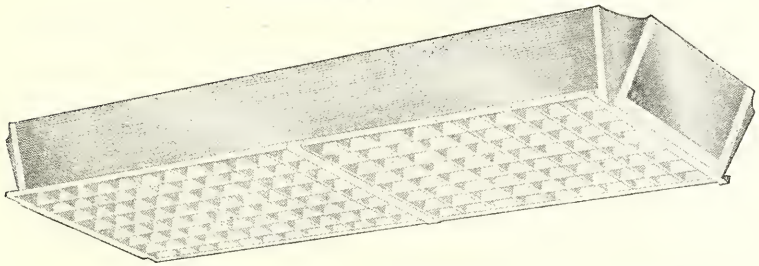
ELECTRO V-MASTER NO. 1042 (Basic Unit + Kit No. 2)

Unusually shallow "V" shape makes this fixture look very compact. Side panels are of special ribbed filter-glass. Panels open from bottom or top for convenience in changing lamps or starters and cleaning.

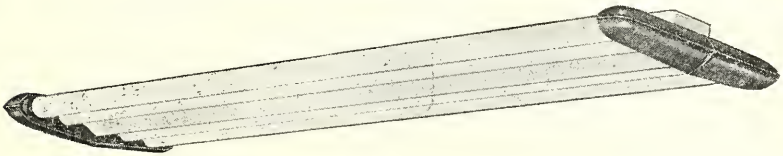
ELECTRO MANUFACTURING CORPORATION

2000 WEST FULTON ST., CHICAGO, ILL.

COMMERCIAL LUMINAIRES



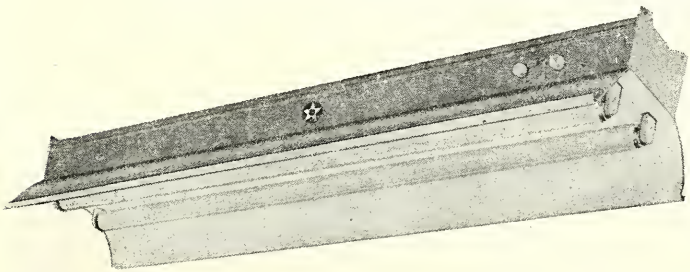
ELECTRO LOUVERLITE NO. 1043 (Basic Unit + Kit No. 3)
A 4-light, 40-watt louvered luminaire with steel louvered panel and filter-glass sides and ends.



ELECTRO SKYLINER NO. 1044 (Basic unit Kit + No. 4)
A compact 4-light, 40-watt luminaire, streamlined, functional. Utilizes highest percentage of lumen output of the bare lamps. No dark spots on ceiling, when fixtures are properly placed. Streamlined bakelite ends in rich walnut grain.
Also Available: No. 1022, two-lite, 40-watt luminaire-same style as 1044.

ELECTRO INDUSTRIAL LUMINAIRES

(All models for Individual or Continuous Hanging)



There is an Electro industrial fluorescent luminaire for every location and requirement.

Model B101. - 2-40 watt.
SPECIFICATIONS: Overall reflector width $12\frac{1}{2}''$; overall height including reflector, $6\frac{5}{8}''$; length $49\frac{1}{4}''$; channel width $6\frac{1}{4}''$; shipping weight 26 lbs. Reflector surface white "Liquid Plastic". Outside finish grey "Liquid Plastic"; channel of 20 gauge metal for lifetime use. Operates 110–125 volts, 60 cycle, A.C. only. Has new type captive latch fastening for attaching reflector. Couplers join any number of units end to end. Entire unit can be easily converted to B105*

Model B201. - 2-100 watt.
SPECIFICATIONS: Reflector width $16\frac{3}{4}''$; height with reflector $8\frac{5}{16}''$; overall length $62\frac{1}{2}''$; channel width $8''$; shipping weight 45 lbs. Easily accessible starters on channel. reflector; surface white "Liquid Plastic"; channel of 20 gauge metal for lifetime use. Operating voltages 110–125 volts. 60 cycle. A.C. only.

Model B105.* - 3-40 watt.
SPECIFICATIONS: reflector width $12\frac{1}{2}''$; overall height including reflector $6\frac{5}{8}''$; overall length $49\frac{1}{2}''$; channel width $6\frac{1}{4}''$; shipping weight 34 lbs. Easily accessible starters on side of top channel. Captive latch arrangement for attaching reflector. Couplers join any number of units end to end. Other features Same as B101.

All industrial units also available with porcelain reflectors.

ELECTRIC SERVICE MANUFACTURING CO.

Designers of *Transportation Lighting*

17th & Cambria Streets, Philadelphia 32, Pennsylvania

District Office and Warehouse
111 No. Canal St., Chicago 6, Ill.

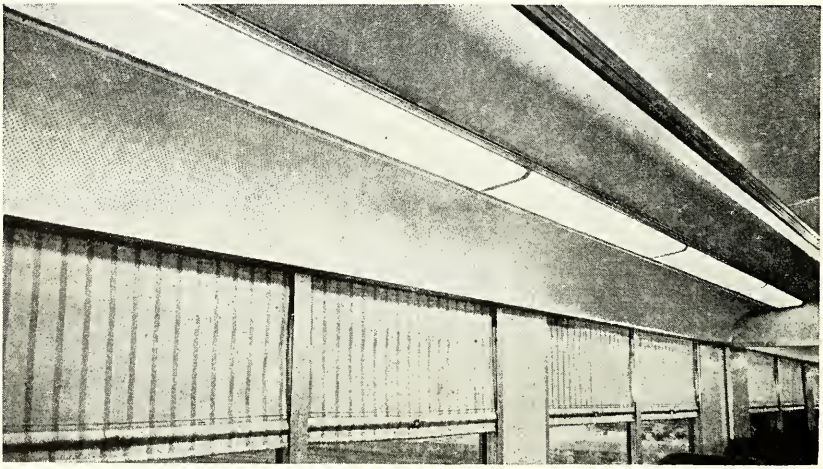
Branch Offices
50 Church St., New York 7, N. Y.
235 Fourth Ave., Pittsburgh 22, Pa.

88 Broad St., Boston 10, Mass.
General Motors Bldg., Detroit 2, Mich.

Direct Representatives in Atlanta, Buffalo, Dayton, St. Louis, Dallas and Washington, D. C.

Designers and manufacturers of Keystone Lighting Equipment for transportation vehicles, including Buses, Trolley Buses, Steam and Electric Railway Cars, Locomotives, Aircraft and Boats. Equipment includes interior lighting, rear-end lighting, step-lighting, head-lighting and numerous other specialized lighting units.

While we catalog many lighting units for transportation vehicles, in most cases, detailed preliminary engineering is necessary to assure a high standard of illumination and styling. The size, shape and color of the space to be lighted, the available power supply and other factors are controlled by the vehicle builder. Our artists, illuminating engineers and designers create and manufacture lighting equipment to meet the requirements of all types of transportation vehicles.

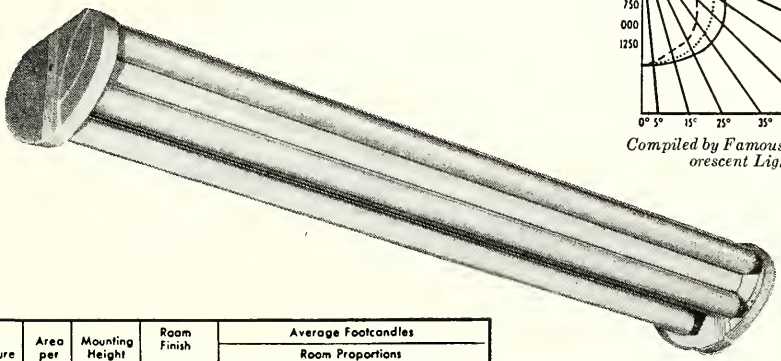


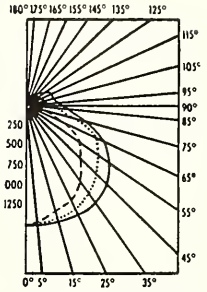
Keystone Fluorescent Lighting as designed for new overnight coaches.

FAMOUS FLUORESCENT LIGHT CO.

762 NORTH OGDEN AVENUE • CHICAGO 22, ILLINOIS

Fluorescent 4-40 Commercial unit
Model No. 440-OC





Compiled by Famous Fluorescent Light Co

Fixture Spacing	Area per Fixture Sq. Ft.	Mounting Height Above Floor	Room Finish Walls & Ceiling	Average Footcandles — Room Proportions: Large W = 4xM.H.	Medium W = 2xM.H.	Small W = 1½xM.H.
INDIVIDUAL OR GROUP SPACING						
6'x6'	36	8'-10'	Light**	125	121	106
			Medium*	115	112	96
7'x7'	49	8'-10'	Light	92	89	78
			Medium	85	82	71
8'x8'	64	8'-10'	Light	70	68	59
			Medium	65	63	54
9'x9'	81	9'-11'	Light	55	51	45
			Medium	51	47	41
10'x10'	100	10'-12'	Light	45	42	37
			Medium	42	38	33
11'x11'	121	12'-14'	Light	36	33	28
			Medium	33	31	25
CONTINUOUS ROW SPACING						
11'	44	11'-13'	Light	99	92	80
			Medium	92	84	72
12'	48	12'-14'	Light	91	84	70
			Medium	84	77	63
13'	52	12'-14'	Light	84	78	64
			Medium	78	71	58
14'	56	14'-16'	Light	78	72	55
			Medium	72	66	47
15'	60	14'-16'	Light	73	67	52
			Medium	67	62	44
16'	64	14'-16'	Light	68	63	48
			Medium	63	58	41

Footcandles shown are for WHITE lamps: For Daylight Lamps, multiply the values by 0.85.
**Light: Ceiling Refl. 80%, Wall 60% *Medium: Ceiling Refl. 60%, Wall 40%

Compiled by Famous Fluorescent Light Co.

Underwriters Laboratories approved

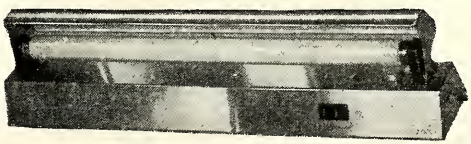
BALLAST—High power factor—correction 95% plus —60 cycle A. C.—110 . 125 volts—four 40 watt lamps

HEAVY gauge all steel construction—white baked enamel end plates and reflector —completely wired

Length 48¼″ Width 11″—Shipping weight 35 #

Fluorescent Chrome Bracket

Model No. C-115-14 Watt C-118-15 Watt or C-124-20 watt



BALLAST—High or low power factor—60 cycle A. C. —110 . 125 volts one 14–15 or 20 watt lamp

Chrome finish on copper over steel—rustproof guaranteed

Equipped with or without convenience outlet and deflectors

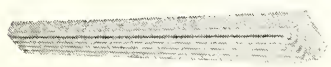
Length 19½″ width 3¼″

OCCASIONAL lighting in kitchen, bathroom, work room and many commercial uses

FEDERAL ELECTRIC COMPANY Inc.

8700 S. State St., Chicago 19, Ill.

STRIPLITE



**LD 939B2 has 9″ raceway as distinguished from the LD 934B2 which has a 4″ raceway.

No. lamps	Catalog No.	Wattage	Basic Weight	MF =
1	LD 934B1	55	18 #	.75
1	LD 934B116*	105	34 #	↑
2	LD 934B2	105	21 #	6
2	LD 939B2**	105	35 #	—
3	LD 939B3	160	40 #	80
3	LD 939B316*	315	74 #	↓
4	LD 939B4	210	43 #	
6	LD 939B6	315	60 #	

*Two 8′ fixtures used in tandem.

Ceiling	75%			50%		
Walls	50%	30%	10%	50%	30%	10%
Room Index	Utilization Factors					
J	.37	.31	.28	.37	.31	.29
I	.45	.41	.37	.44	.40	.38
H	.49	.46	.43	.48	.45	.42
G	.54	.50	.46	.52	.50	.47
F	.57	.53	.49	.55	.53	.49
E	.61	.59	.54	.61	.57	.55
D	.66	.62	.59	.65	.61	.59
C	.69	.65	.60	.66	.63	.60
B	.71	.67	.65	.69	.65	.64
A	.73	.79	.67	.71	.68	.65

INDUSTRIALITE

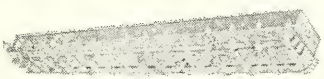


2	LD 755B2	105	46 #	MF = .70 ↑ 0 — 80 ↓
3	LD 755B3	160	51 #	
3	LD 755B316*	315	92 #	
4	LD 755B4	210	56 #	

*Two 8′ fixtures used in tandem.

J	.36	.29	.24	.35	.29	.24
I	.45	.39	.35	.44	.38	.34
H	.49	.44	.40	.48	.44	.40
G	.53	.48	.44	.52	.48	.44
F	.56	.51	.47	.54	.50	.47
E	.61	.57	.53	.60	.56	.53
D	.66	.62	.58	.64	.62	.58
C	.68	.65	.62	.66	.63	.62
B	.72	.69	.66	.70	.67	.66
A	.74	.70	.68	.72	.69	.67

CURVELITE

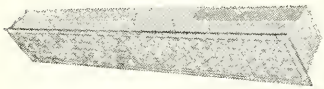


2	LD 935B2	105	51 #	MF = .70 ↑ 9 — 65 ↓
3	LD 935B3	160	56 #	
3	LD 935B316*	315	92 #	
4	LD 935B4	210	59 #	

*Two 8′ fixtures used in tandem.

J	.33	.29	.27	.32	.29	.27
I	.40	.37	.35	.38	.35	.34
H	.43	.41	.39	.42	.39	.38
G	.47	.44	.42	.45	.43	.41
F	.50	.47	.44	.47	.45	.43
E	.54	.51	.48	.51	.49	.47
D	.57	.54	.51	.54	.52	.50
C	.59	.56	.53	.56	.54	.51
B	.61	.58	.56	.58	.55	.54
A	.63	.60	.58	.60	.57	.55

FLUSHLITE (with louvers)

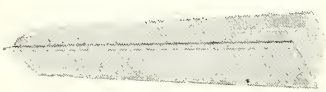


2	LD 981B2L	105	73 #	MF = .70 ↑ 0 — 65 ↓
3	LD 981B3L	160	79 #	
3	LD 981B316L*	315	139 #	
4	LD 981B4L	210	81 #	

*Two 8′ fixtures used in tandem.

J	.32	.28	.25	.32	.28	.25
I	.40	.36	.34	.39	.35	.33
H	.43	.39	.37	.42	.39	.37
G	.46	.43	.41	.45	.43	.41
F	.48	.45	.43	.47	.45	.43
E	.52	.50	.48	.51	.49	.47
D	.56	.54	.52	.55	.53	.51
C	.57	.55	.53	.56	.54	.52
B	.60	.58	.56	.59	.57	.55
A	.61	.59	.57	.60	.58	.57

FLUSHLITE (with Skytex glass)

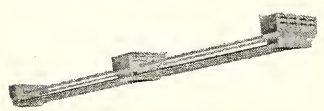


2	LD 981B2G	105	76 #	MF = .70 ↑ 0 — 60 ↓
3	LD 981B3G	160	82 #	
3	LD 981B316G*	315	142 #	
4	LD 981B4G	210	84 #	

*Two 8′ fixtures used in tandem.

J	.30	.26	.24	.29	.26	.24
I	.37	.34	.32	.36	.33	.31
H	.40	.38	.36	.39	.37	.35
G	.43	.40	.39	.42	.40	.38
F	.45	.43	.40	.44	.42	.40
E	.48	.46	.44	.47	.46	.44
D	.52	.49	.47	.50	.49	.47
C	.53	.51	.49	.52	.50	.49
B	.55	.53	.52	.53	.52	.51
A	.56	.54	.53	.55	.53	.52

STREAMLITE



2	LD 922B8*	105	22 #	MF = .75 ↑ 50 — 50 ↓
4	LD 924B8*	210	32 #	

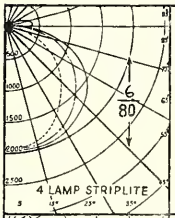
*Last number designates length of continuous run in eight foot multiples, e.g. Cat. #LD 922B48 would designate a 2 lamp Streamlite in a 48′ continuous line.

J	.28	.22	.19	.24	.20	.17
I	.35	.29	.25	.30	.26	.22
H	.39	.33	.30	.34	.30	.26
G	.44	.38	.34	.38	.33	.30
F	.48	.42	.37	.41	.36	.32
E	.53	.47	.42	.46	.41	.37
D	.58	.52	.46	.49	.45	.41
C	.61	.55	.50	.52	.47	.44
B	.66	.61	.56	.56	.51	.48
A	.69	.64	.59	.59	.54	.51

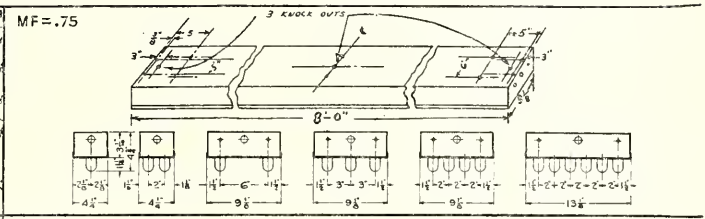
FEDERAL ELECTRIC COMPANY Inc.

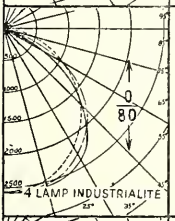
CANDLE POWER DISTRIBUTION CURVES

OUTLINE DRAWINGS

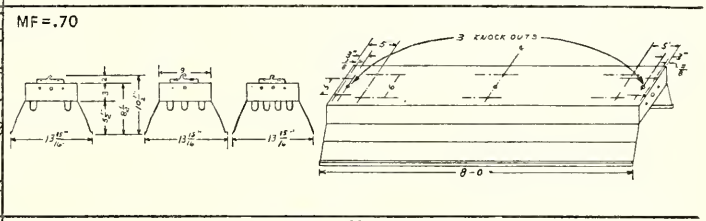


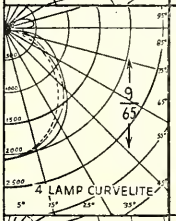
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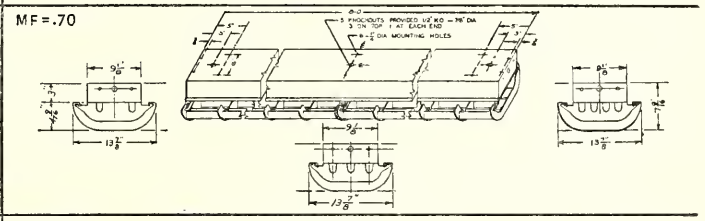


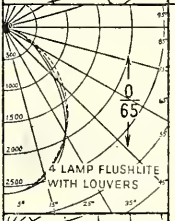
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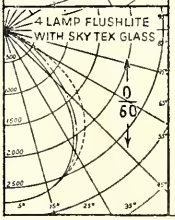




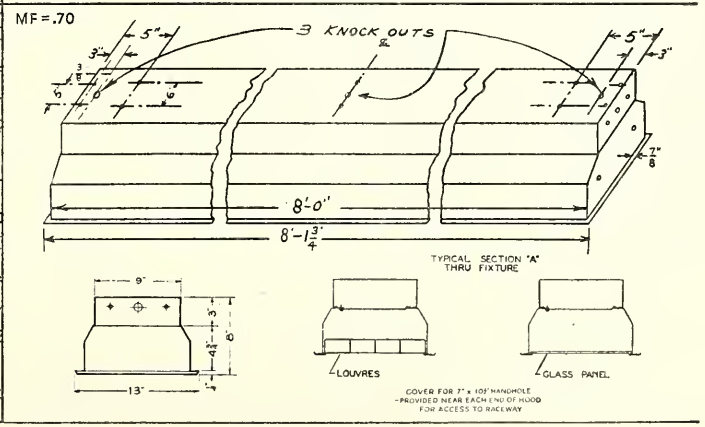
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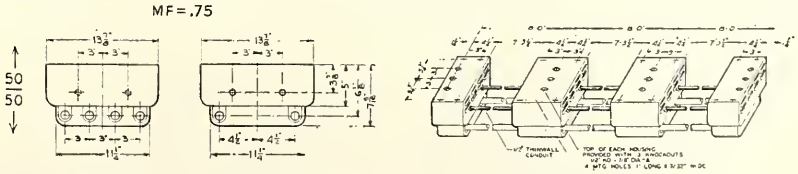




MF=.70



MF=.75

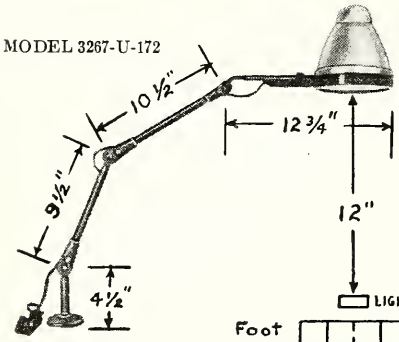


Illumination Data from Tests in Laboratory of Federal Electric Co.

The Fostoria Pressed Steel Corp.
Fostoria, Ohio

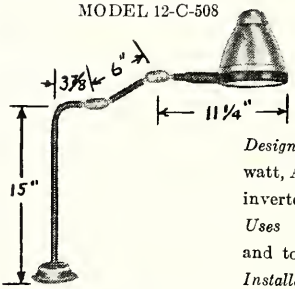
MODELS WITH NO. 12 "U" TYPE REFLECTORS

MODEL 3267-U-172



Light cell 16⅞ inches from light center. All readings taken 12 inches from bottom of reflector perpendicular to beam. Standard finish. 100 watt, A-21, IF lamp.

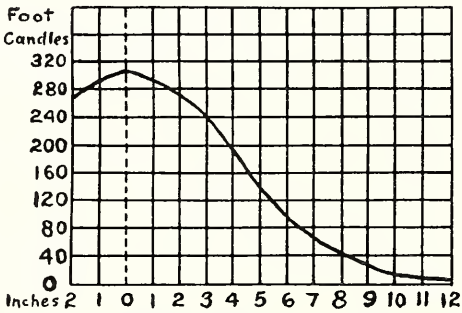
MODEL 12-C-508



Designed for 100 watt, A-21, IF lamp inverted.

Uses Inspection and tool machines.

Installed on large presses, millers or inspection tables where a narrow distribution of relatively high level is indicated.



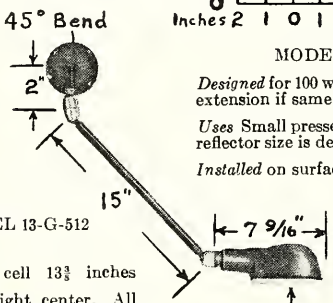
Data by Fostoria laboratory

MODELS WITH NO. 13 "H" TYPE REFLECTORS

Designed for 100 watt, A-21, IF lamp. Smaller lamps may be used with socket extension if same illumination pattern is desired.

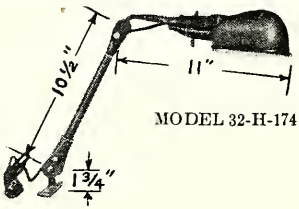
Uses Small presses, Do-all combinations and other tool machines where small reflector size is desirable.

Installed on surface of machine.

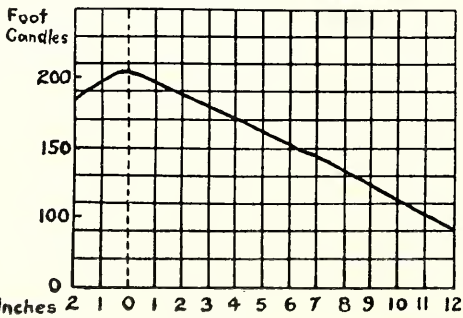


MODEL 13-G-512

Light cell 13⅜ inches from light center. All readings taken 12 inches from bottom of reflector perpendicular to beam. High temperature reflective Infra-red baked white reflective surfaces. 100 watt, A-21, IF lamp.



MODEL 32-H-174



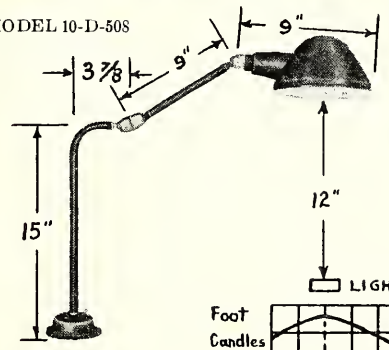
Data by Fostoria laboratory

The Fostoria Pressed Steel Corp.

Fostoria, Ohio

MODELS WITH NO. 10 "P" TYPE REFLECTORS

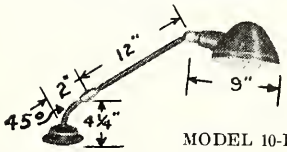
MODEL 10-D-508



Designed for 100 watt, A-21, IF lamp. Smaller lamps may be used with socket extension if same illumination pattern is desired. May be equipped with clear, daylight, or opalescent lens and retaining ring.

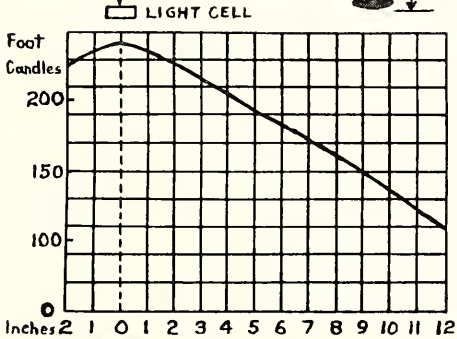
Uses On presses, lathes, or bench.

Installed Model 10-D-508 may be installed in horizontal position on automatic screw machine.



MODEL 10-F-512

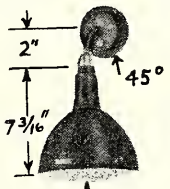
Light cell 13⅞ inches from light center. All readings taken 12 inches from bottom of reflector perpendicular to beam. Standard finish. 100 watt, A-21, IF lamp.



Data by Fostoria Laboratory

MODELS WITH NO. 26 "C" TYPE REFLECTORS

MODEL 26-X-512

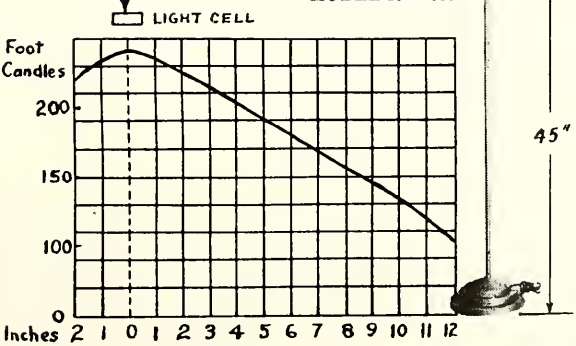


Designed for all reflector lamps including therapeutic, ultra-violet, and lighting lamps (i.e., R-40 and PAR-38 lamps).

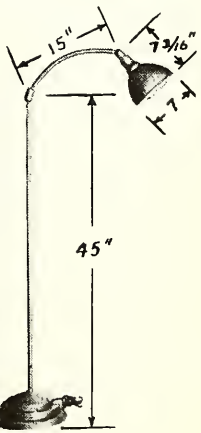
Uses Spot or flood lighting; ultra-violet for health; hard glass heat lamp for therapeutic uses and hair drying.

Installed in bathrooms, shower, locker rooms, dressing rooms, area flood lighting or spot lighting.

Light cell 13⅞ inches from light center. All readings taken 12 inches from bottom of reflector perpendicular to beam. Standard finish. 100 watt, A-21, IF lamp.



MODEL 26-H-516



Data by Fostoria Laboratory

THE FRINK CORPORATION

and subsidiaries

STERLING BRONZE COMPANY, INC.

BARKON-FRINK TUBE LIGHTING CORPORATION

PLANNED LIGHTING SINCE 1857

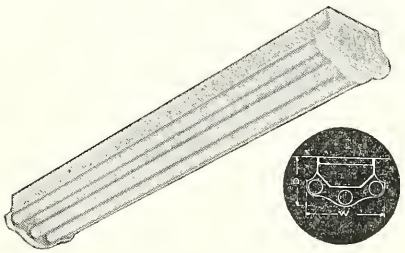
FOR THE NAME OF YOUR NEAREST JOBBER, WRITE TO THE FRINK CORPORATION, 27-01 BRIDGE PLAZA NORTH, LONG ISLAND CITY 1, NEW YORK

The Frink Corporation provides a complete engineering and manufacturing lighting service. All Frink L-I-N-O-L-I-T-E fluorescent fixtures are designed to provide the "Ultimate in Fluorescent Lighting." For special application either fluorescent or incandescent fixtures can be Frink custom built to suit your requirements.

All Frink fixtures are representative of the efficient design and quality workmanship associated with the Frink name since 1857. All fixture designs are carefully pre-tested in our own laboratory to insure many years of efficient, trouble-free service with minimum maintenance.

The Frink engineering department is available to custom engineer the ultimate in lighting to suit all requirements for light intensity, brightness, contrast maintenance and architectural fitness. Inquiries are invited.

FRINK LINOLITE SERIES 3



A good looking, highly efficient bare lamp unit for stores, public rooms, etc. This fixture is easily installed and readily maintained. This fixture can be ceiling or hanger mounted.

Type Number	Lamps		Dimensions		
	Per Fixt.	Size	Width	Depth	Length
3-248	2	48″—40W	8¼″	5¼″	48⅝″
3-348	3	48″—40W	8¼″	5¼″	48⅝″
3-448	4	48″—40W	8¼″	5¾″	48⅝″

For a continuous run, order one individual unit type 3——, and the remaining units type 3——CR.

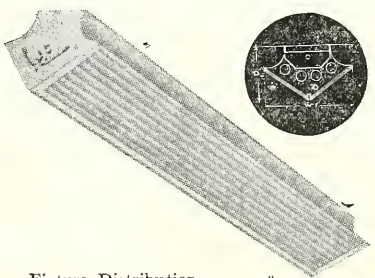
Fixture Distribution

Series	% Up	% Down
3-248	28	56
3-348	26	54
3-448	23	51

Coefficient of Utilization

Large Rm. (W=4H)			Med. Rm. (W=2H)			Small Rm. (W=H)		
Light Finish	Med. Finish	Dark Finish	Light Finish	Med. Finish	Dark Finish	Light Finish	Med. Finish	Dark Finish
.66	.57	.51	.57	.49	.43	.44	.37	.32
.63	.54	.49	.54	.47	.41	.42	.35	.31
.58	.51	.46	.51	.44	.39	.40	.32	.29

FRINK LINOLITE SERIES 4



A semi direct unit, with an ingenious invisible hinge, and a full length dust vent which greatly simplifies maintenance, and provides good all around lighting for offices, stores, showrooms, libraries, schools, etc.

Type Number	Lamps		Dimensions		
	Per Fixt.	Size	Width	Depth	Length
4-248	2	48″—40W	11⅞″	7¼″	48⅝″
4-348	3	48″—40W	11⅞″	7¼″	48⅝″
4-448	4	48″—40W	13½″	8″	45⅝″

Fixture Distribution

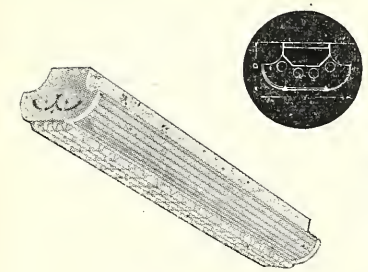
Series	% Up	% Down
4-248	32	47
4-348	29	43
4-448	26	41

Coefficient of Utilization

Large Rm. (W=4H)			Med. Rm. (W=2H)			Small Rm. (W=H)		
Light Finish	Med. Finish	Dark Finish	Light Finish	Med. Finish	Dark Finish	Light Finish	Med. Finish	Dark Finish
.57	.47	.41	.46	.37	.32	.28	.22	.19
.52	.42	.37	.42	.34	.29	.25	.20	.17
.48	.39	.34	.39	.31	.27	.24	.18	.15

THE FRINK CORPORATION

FRINK LINOLITE SERIES 5

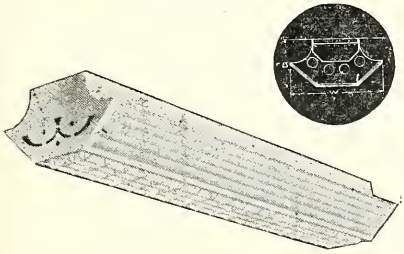


A semi direct unit combining highly effective illuminating qualities with attractive appearance. Can be provided with fluted glass or louvered center panel. The unit can be ceiling or hanger mounted.

Type Number	Lamps		Dimensions			Description
	Per Fixt.	Size	Width	Depth	Length	
5-248	2	48″—40W	12¼″	6¾″	48⅝″	Center glass
5-348	3	48″—40W	12¼″	6¾″	48⅝″	Center glass
5-448	4	48″—40W	13¼″	7″	48⅝″	Center glass
5-248-L	2	48″—40W	12¼″	7¼″	48⅝″	Center lou.
5-348-L	3	48″—40W	12¼″	7¼″	48⅝″	Center lou
5-448-L	4	48″—40W	13½″	7½″	48⅝″	Center lou.

Fixture Distribution			Coefficient of Utilization								
			Large Rm. (W=4H)			Med. Rm. (W=2H)			Small Rm. (W=H)		
Series	% Up	% Down	Light Finish	Med. Finish	Dark Finish	Light Finish	Med. Finish	Dark Finish	Light Finish	Med. Finish	Dark Finish
5-248 & L	32	47	.57	.47	.41	.46	.37	.32	.28	.22	.19
5-348 & L	29	43	.52	.42	.37	.42	.34	.29	.25	.20	.17
5-448 & L	26	41	.48	.39	.34	.39	.31	.27	.24	.18	.15

FRINK LINOLITE SERIES 6

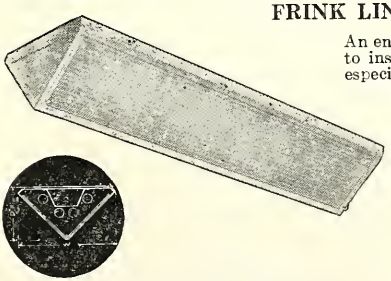


A finely proportioned and highly efficient semi-direct fixture. Combines the economy of a production unit with distinctive "custom lighting" appearance. Can be provided with fluted glass or louvered center panel, ceiling or hanger mounted.

Type Number	Lamps		Dimensions			Description
	Per Fixt.	Size	Width	Depth	Length	
6-248	2	48″—40W	12¼″	6¾″	48⅝″	Center glass
6-348	3	48″—40W	12¼″	6¾″	48⅝″	Center glass
6-448	4	48″—40W	14″	7″	48⅝″	Center glass
6-248-L	2	48″—40W	12¼″	7¼″	48⅝″	Center louvered
6-348-L	3	48″—40W	12¼″	7¼″	48⅝″	Center louvered
6-448-L	4	48″—40W	14″	7½″	48⅝″	Center louvered

Fixture Distribution			Coefficient of Utilization								
			Large Rm. (W=4H)			Med. Rm. (W=2H)			Small Rm. (W=H)		
Series	% Up	% Down	Dark Finish	Med. Finish	Light Finish	Dark Finish	Med. Finish	Light Finish	Dark Finish	Med. Finish	Light Finish
6-248 & L	32	47	.57	.47	.41	.46	.37	.32	.28	.22	.19
6-348 & L	29	43	.52	.42	.37	.42	.34	.29	.25	.20	.17
6-448 & L	26	41	.48	.39	.34	.39	.31	.27	.24	.18	.15

FRINK LINOLITE SERIES 7



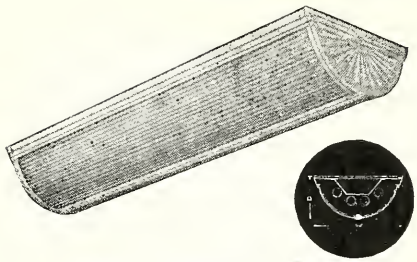
An enclosed semi-direct unit with hinged glass panels, designed to insure long life with minimum maintenance. The unit is especially suitable for ceiling mounting in continuous runs.

Type Number	Lamps		Dimensions		
	Per Fixt.	Size	Width	Depth	Length
7-248	2	48″—40W	15¾″	8½″	48⅝″
7-348	3	48″—40W	15¾″	8½″	48⅝″
7-448	4	48″—40W	15¾″	8½″	48⅝″

Fixt. Distribution			Coefficient of Utilization								
			Large Rm. (W=4H)			Med. Rm. (W=2H)			Small Rm. (W=H)		
Series	% Up	% Down	Dark Finish	Med. Finish	Light Finish	Dark Finish	Med. Finish	Light Finish	Dark Finish	Med. Finish	Light Finish
7-248	6	53	.51	.46	.44	.42	.39	.37	.30	.26	.24
7-348	5	50	.48	.43	.41	.40	.37	.35	.28	.25	.23
2-448	5	48	.46	.42	.40	.39	.36	.34	.27	.24	.22

THE FRINK CORPORATION

FRINK LINOLITE SERIES 8

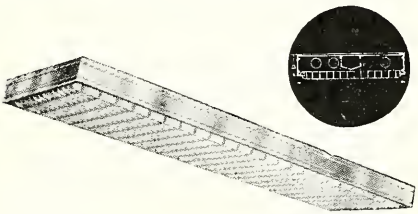


An enclosed semi-direct unit with hinged glass sides and decorative molding. The fine appearance of this fixture makes it especially adaptable for banks, showrooms, libraries, etc. The fixture can be installed either singly or in continuous runs.

Type Number	Lamps		Dimensions		
	Per Fixt.	Size	Width	Depth	Length
8-248	2	48″—40W	15½″	7¼″	48⅝″
8-348	3	48″—40W	15¼″	7¼″	48⅝″
8-448	4	48″—40W	15¼″	7¼″	48⅝″

Series	Fixture Distribution		Coefficient of Utilization								
	% Up	% Down	Large Rm. (W=4H)			Med. Rm. (W=2H)			Small Rm. (W=H)		
			Light Finish	Med. Finish	Dark Finish	Light Finish	Med. Finish	Dakr Finish	Light Finish	Med. Finish	Dark Finish
8-248	6	53	.51	.46	.44	.42	.39	.37	.30	.26	.24
8-348	5	50	.48	.43	.41	.40	.37	.35	.28	.25	.23
8-448	5	48	.46	.42	.40	.39	.36	.34	.27	.24	.22

FRINK LINOLITE SERIES 11

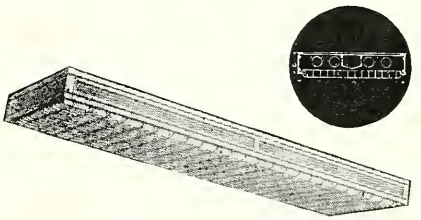


The distinctive side molding and depth of only 3 inches combine to make this fixture an outstanding example of modern Frink engineered lighting. Provided with a hinged louver or glass bottom. The fixture can be readily installed either ceiling mounted or on hangers, singly or in continuous runs.

Type Number	Lamps		Dimensions			Description
	Per Fixt.	Size	Width	Depth	Length	
11-248-G	2	48″—40W	11½″	3″	49¼″	Gl. bot.
11-448-G	4	48″—40W	15½″	3″	49¼″	Gl. bot.
11-248-L	2	48″—40W	11½″	3″	49¼″	*Lou. bot.
11-448-L	4	48″—40W	15½″	3″	49¼″	*Lou. bot.

Series	Fixture Distribution		Coefficient of Utilization								
	% Up	% Down	Large Rm. (W=4H)			Med. Rm. (W=2H)			Small Rm. (W=H)		
			Light Finish	Med. Finish	Dark Finish	Light Finish	Med. Finish	Dark Finish	Light Finish	Med. Finish	Dark Finish
11-248G&L (flush)	0	48	.44	.41	.40	.39	.36	.34	.31	.28	.26
11-448G&L (flush)	0	42	.38	.36	.34	.33	.30	.29	.27	.24	.22
11-248G&L (Susp.)	41	30	.48	.40	.33	.41	.34	.26	.31	.24	.19
11-448G&L (Susp.)	47	25	.48	.37	.30	.40	.32	.24	.30	.22	.17

FRINK LINOLITE SERIES 12



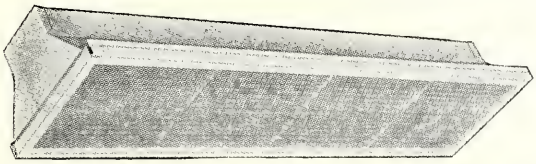
A wafer-thin fixture of fine appearance and high efficiency, with hinged louver or glass bottom and luminous sides, adaptable for almost all ceiling conditions. The fixtures can be readily installed either ceiling mounted or on hangers, singly or in continuous runs.

Type Number	Lamps		Dimensions			Description
	Per Fixt.	Size	Width	Depth	Length	
12-248-G	2	48″—40W	11½″	3″	49¼″	Gl. bot.
12-448-G	4	48″—40W	15½″	3″	49¼″	Gl. bot.
12-248-L	2	48″—40W	11½″	3″	49¼″	Lou. bot.
12-448-L	4	48″—40W	15½″	3″	49¼″	Lou. bot.

Series	Fixture Distribution		Coefficient of Utilization								
	% Up	% Down	Large Rm. (W=4H)			Med. Rm. (W=2H)			Small Rm. (W=H)		
			Light Finish	Med. Finish	Dark Finish	Light Finish	Med. Finish	Dark Finish	Light Finish	Med. Finish	Dark Finish
12-248G&L (flush)	3	47	.45	.41	.40	.39	.36	.33	.31	.28	.25
12-448G&L (flush)	2	40	.37	.35	.33	.33	.30	.28	.27	.23	.21
12-248G&L (Susp.)	41	30	.48	.40	.33	.41	.34	.26	.31	.24	.19
12-448G&L (Susp.)	42	25	.48	.37	.30	.40	.32	.24	.30	.22	.17

THE FRINK CORPORATION

FRINK SHALLOW TROFFERS
LINOLITE SERIES 10 FOR J. M. CEILING
LINOLITE SERIES 15 FOR PLASTER CEILING





Series 10



Series 15

These fixtures are equipped with either louvers, glass diffuser panels or lenses to "condition" the quality of illumination to suit the particular requirements. Fixtures completely assembled and wired for easy installation.

When installing these troffers on a J. M. ceiling, set unit on frame of opening and snap lens, glass or louver retainer in J.M. frame. For plaster ceilings install by means of yoke or set adjustable clip attached to unit, on frame of ceiling opening.

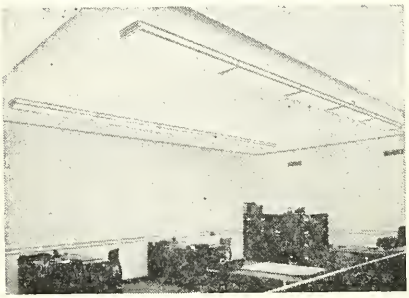
Type Number	Lamps: Per Fixt.	Lamps: Size	Dimensions: Width	Dimensions: Depth	Dimensions: Length	Description
10-148L	1	48″—40W	12″	7 1/8″	48″	Hinged Louver
10-248L	2	48″—40W	12″	7 1/8″	48″	Hinged Louver
10-348L	3	48″—40W	12″	7 1/8″	48″	Hinged Louver
10-148G	1	48″—40W	12″	7 1/8″	48″	Laid-in Fluted Glass
10-248G	2	48″—40W	12″	7 1/8″	48″	Laid-in Fluted Glass
10-348G	3	48″—40W	12″	7 1/8″	48″	Laid-in Fluted Glass
10-148HG	1	48″—40W	12″	7 1/8″	48″	FOR J.M. CEILING Hinged Fluted Glass
10-248HG	2	48″—40W	12″	7 1/8″	48″	Hinged Fluted Glass
10-348HG	3	48″—40W	12″	7 1/8″	48″	Hinged Fluted Glass
10-148HO	1	48″—40W	12″	7 1/8″	48″	Laid-in Holo. Lens 11F12
10-248HO	2	48″—40W	12″	7 1/8″	48″	Laid-in Holo. Lens 11F12
10-348HO	3	48″—40W	1**	7 1/8″	48″	Laid-in Holo. Lens 11F12
10-148HOH	1	48″—40W	12″	7 1/8″	48″	Hinged Holo. Lens 11F12
10-248HOH	2	48″—40W	12″	7 1/8″	48″	Hinged Holo. Lens 11F12
10-348HOH	3	48″—40W	12″	7 1/8″	48″	Hinged Holo. Lens 11F12
15-148	1	48″—40W	12″	6 3/4″	48″	Open Troffer
15-248	2	48″—40W	12″	6 3/4″	48″	Open Troffer
15-348	3	48″—40W	12″	6 3/4″	48″	Open Troffer
15-448	4	48″—40W	12″	6 3/4″	48″	Open Troffer
15-148L	1	48″—40W	12″	6 3/4″	48″	Hinged Louver
15-248L	2	48″—40W	12″	6 3/4″	48″	Hinged Louver
15-348L	3	48″—40W	12″	6 3/4″	48″	Hinged Louver
15-448L	4	48″—40W	12″	6 3/4″	48″	Hinged Louver
15-148G	1	48″—40W	12″	6 3/4″	48″	Laid-in Fluted Glass
15-248G	2	48″—40W	12″	6 3/4″	48″	Laid-in Fluted Glass
15-348G	3	48″—40W	12″	6 3/4″	48″	FOR PLASTER CEILING Laid-in Fluted Glass
15-448G	4	48″—40W	12″	6 3/4″	48″	Laid-in Fluted Glass
15-148HG	1	48″—40W	12″	6 3/4″	48″	Hinged Fluted Glass
15-248HG	2	48″—40W	12″	6 3/4″	48″	Hinged Fluted Glass
15-348HG	3	48″—40W	12″	6 3/4″	48″	Hinged Fluted Glass
15-448HG	4	48″—40W	12″	6 3/4″	48″	Hinged Fluted Glass
15-148HO	1	48″—40W	12″	6 3/4″	48″	Laid-in Holo. Lens 11F12
15-248HO	2	48″—40W	12″	6 3/4″	48″	Laid-in Holo. Lens 11F12
15-348HO	3	48″—40W	12″	6 3/4″	48″	Laid-in Holo. Lens 11F12
15-148HOH	1	48″—40W	12″	6 3/4″	48″	Hinged Holo. Lens 11F12
15-248HOH	2	48″—40W	12″	6 3/4″	48″	Hinged Holo. Lens 11F12
15-348HOH	3	48″—40W	12″	6 3/4″	48″	Hinged Holo. Lens 11F12

Series	Fixture Distribution: % Up	Fixture Distribution: % Down	Coefficient of Utilization: Large Rm. (W=4H) Light Finish	Large Rm. (W=4H) Med. Finish	Large Rm. (W=4H) Dark Finish	Med. Rm. (W=2H) Light Finish	Med. Rm. (W=2H) Med. Finish	Med. Rm. (W=2H) Dark Finish	Small Rm. (W=H) Light Finish	Small Rm. (W=H) Med. Finish	Small Rm. (W=H) Dark Finish
10-148L&G 15-148L&G	0	69	.66	.63	.62	.54	.51	.49	.38	.34	.31
10-248L&G 15-248L&G	0	66	.63	.61	.59	.52	.49	.47	.37	.32	.29
10-348L&G 15-348L&G	0	60	.57	.55	.53	.47	.45	.43	.34	.30	.27









ENGINEERING AND SPECIFICATION DATA

LIGHT DISTRIBUTION. Frink-engineered fixtures are exhaustively tested for effective light distribution and high efficiency consistent with good design.

APPROVAL. Frink fluorescent fixtures are 100% Union made and bear the label of the Underwriters' Laboratories. All meet the standards established by the Department of Water Supply, Gas & Electricity of New York City.

ELECTRICAL CHARACTERISTICS. All Frink fixtures are provided with starters and high power factor ballasts. Standard fixtures are available for operating voltages of 110–125, 199–215, 220–225 volts A. C. 60 cycles. For a slight additional cost fixtures may be wired for 50 cycle operating. Instant start ballasts which eliminate the need for starters, provided at small extra cost.

APPEARANCE. An outstanding characteristic of all Frink fixtures is their fine appearance. All units are examples of the good design, sound engineering and quality workmanship associated with the Frink name since 1857.

FINISH. Frink-engineered equipment features a new high reflection finish baked at a high temperature for maximum durability and light output. It *is* brighter and *stays* brighter.

INSTALLATION. All Frink fixtures are completely wired and assembled. The fixtures can be readily installed and easily maintained. Fixtures can be ceiling mounted or mounted on hangers either singly or in continuous runs. When ordering Frink standard hangers specify the required lengths.

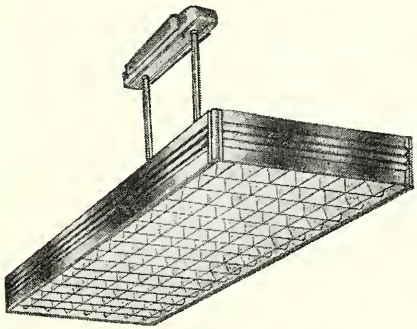
INDIVIDUAL PACKING. All Frink fixtures come packed in custom designed protective containers.

SPECIFICATIONS SUBJECT TO CHANGE WITHOUT NOTICE

GARDEN CITY PLATING & MFG. CO.

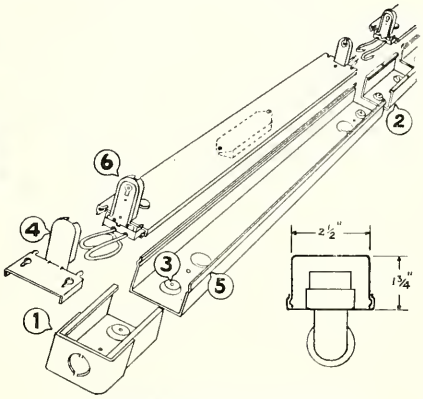
Office & Factory 1750 N. Ashland Ave., Chicago 22, Ill.

New York Office & Warehouse: 600 Broadway, N. Y. 12, N. Y.
Representatives in Principal Cities



No. 7718 H.L.

Fluorescent Unit



No. 8000* Adda-Strip Series

Designed for four forty-watt fluorescent lamps in 49 x 16 x 4 inch frame, with light distribution of 22% uplight and 78% downlight. Also furnished for ceiling mounting. Fixture is designed for continuous runs as well as single unit installation.

Application—Commercial lighting.

Exterior is of heavy gauge aluminum with natural polished extruded aluminum trim. Interior and louvers are finished in Garlite white enamel, baked under 350° temperature and providing high reflectivity in laboratory tests.

Louvers—Hinged for ease of installation of lamps and ready access to interior of fixture.

Wired—Complete with two high power factor two-lamp ballasts and starters for 60 cycle, 110-125 volts AC. Total watts 191.

Also furnished in combination with Garcy Accent (double pivot) lighting, for mounting at end or between fixtures.

(*Write for literature*)

1. Removable splice boxes and covers for each end. Splice chamber is 1½″ long.
2. Couplings for connecting strips in continuous runs, extend 2″ into each channel, brings sockets back to back.
3. Embossed screw holes in end of strip match similarly embossed holes in couplings and end boxes. Strips are aligned perfectly straight and rigid.
4. Metal socket covers prevent end sockets being bent backwards, allowing lamps to fall. Covers prevent sockets from breakage in handling and lamping.
5. Rolled edge channels and covers—Covers can be snapped on and off without screws.
6. Snap Covers—Furnished assembled with ballast and sockets completely wired with extra wire lead at each end.

Designed and constructed for simple installation.

Write for complete catalog section illustrating multiple-lamp Adda-strip, slimline strips etc.

* Trade Mark Reg. U. S. No. 394,728

Listed and approved by Underwriters Laboratories

APPARATUS DEPARTMENT

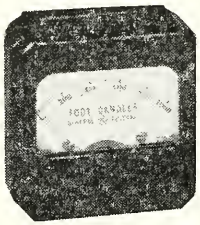
GENERAL ELECTRIC

SCHENECTADY, N. Y.

PHOTOMETRIC DEVICES

Type DW-58 Exposure Meter A precision instrument for determining exposure for either black-and-white or color pictures—movies or stills. Easily converted for use as light meter.

Type DW-40 Light Meter Practical, nontechnical, direct-reading. Range, from 0 to 100 ft-c, can be increased to 1000 ft-c through use of accompanying 10 to 1 multiplier. Order from G-E Lamp Dept., Nela Park, Cleveland, Ohio.

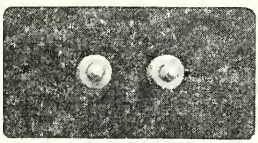


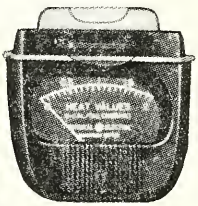
LIGHT METER



EXPOSURE METER

LIGHT CELL





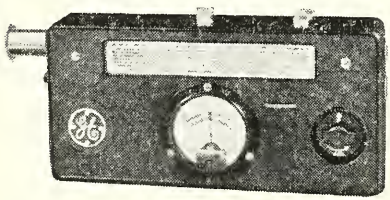
RADIATION METER

G-E Photovoltaic Cell Silver-plated contacts, mounted in Textolite molded case—available in several forms and can be made to specifications to meet special requirements.

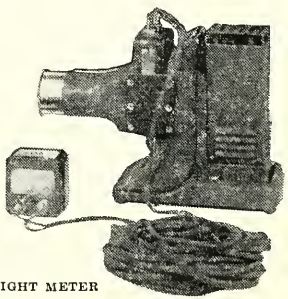
Radiation Meter Small, portable, direct-reading instrument measuring solar radiation. Used in agricultural experiments, weather studies, laboratory tests, and in advanced educational institutions.

Luckeish-Taylor Brightness Meter A portable, high-precision instrument with an accuracy comparable to that of a bar photometer. Scale rating from 2 to 50 ft-lamberts with multiplying filters which increase range from 0.002 to 50,000 ft-lamberts.

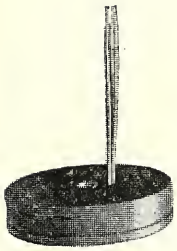
Projection Light Meter Used mainly for demonstration purposes in projecting scales of light-responding instruments on screens. The projector can also be used to project 2 by 2 in. slides. Same range as DW-40 light meter.



BRIGHTNESS METER

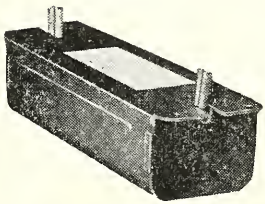


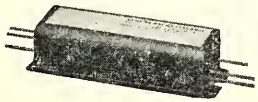
PROJECTION LIGHT METER



Ballast for Circline Lamps This ballast, functionally designed for use with the 12-in. Circline fluorescent lamp departs radically from the conventional ballast shape and construction. It takes the form of a flat disk, with a center hole for mounting. This makes it easily adaptable to assembly on the stem of a portable lamp, and to concealment in the lamp base. Equally adaptable to wall or ceiling fixtures. Leads are brought out through the cover plate and threaded through the lamp stem for connection to the fluorescent lamps. Ballast is available in either single-lamp, uncorrected-, or high-power-factor design, or Tulamp high-power-factor design. Cat. No. 59G420 has a diameter of 6 in. and a height of $1\frac{3}{4}$ in. diameter. All three ballasts operate on 110–125-volt, 60-cycle circuits. Write for Bulletin GEA-3293F.

Ballast for Slimline Lamps Special ballasts have been developed for the operation of instant-starting Slimline "F" lamps. These ballasts are of the high-voltage type, and make possible the elimination of all separate starting equipment from the circuit. Single-lamp ballasts are designed in both uncorrected- and high-power-factor ratings, and Tulamp ballasts in high-power-factor design. All ratings are made in the two-way-lead case style. The instant-starting lamps can be operated at either 100 or 200 milliamperes, and ballast ratings are provided for either current value. All these ballasts operate on 110–125 volt, 60-cycle circuits. Write for Bulletin GEA-3293.





Tulamp High-Power-Factory Ballasts Tulamp high-power-factor ballasts are available for the operation of 15-watt, 20-watt, 30-watt, 40-watt, and 100-watt fluorescent lamps. A wide variety of ratings is offered, including standard, intermediate, and small-cross-section ballasts with built-in compensator, and listings for applications which require no compensator. Many of these ballasts offer the two-way-lead design. Listings include ratings for both 60- and 50-cycle current, with circuit voltages ranging from 110–125 to 240–280 volts. All of these ballasts have a minimum line power factor of 95 per cent at rated lamp watts input and nominal voltage ratings. Write for Bulletin GEA-3293.

Single-Lamp High-Power-Factor Ballasts



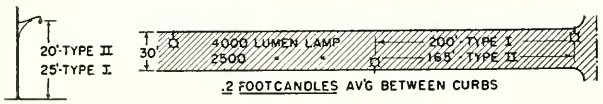
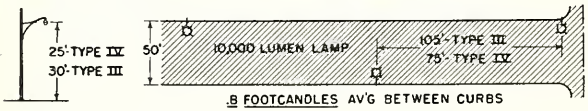
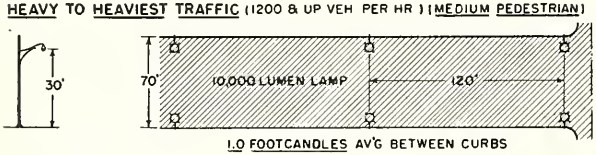
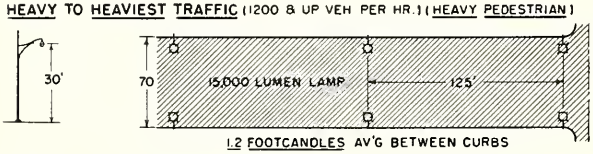
These ballasts, generally of small cross-section, are easily adaptable to installations in restricted spaces, where the need is for a single lamp. Either a simple series reactor or a high-reactance autotransformer is used in their design, with shunt capacitance added. Ratings are listed for both 60- and 50-cycle current operation, with circuit voltages ranging from 110–125 to 240–280 volts. Write for Bulletin GEA-3293.

GENERAL ELECTRIC

SCHENECTADY, N. Y.

Traffic Lighting Equipment—Floodlights—Traffic Signals and Controllers

RECOMMENDED PRACTICE OF STREET LIGHTING—1945

Illuminating Engineering Society Average Recommendations	Most Effective G-E Equipment			
	LUMINAIRE	IES TYPE LIGHT DIST'BN	SPACING, FT.	AVERAGE FOOT-CANDLES
VERY LIGHT TRAFFIC (UNDER 150 VEH. PER HR.) (LIGHT OR NO PEDESTRIAN)  	79-VR 4000L. Lamp	I	200	0.21
	79-SO 2500L. Lamp	II	165	0.21
LIGHT TRAFFIC (150-500 VEH. PER HR.) (LIGHT TO MEDIUM PEDESTRIAN)  	79-R #4110 Refr.)	III	100–150	0.42–0.63
MEDIUM TRAFFIC (500-1200 VEH PER HR.) (MEDIUM PEDESTRIAN)  	79-R (#4110 Refr.)	III	105	0.82
	79-D #207 Diffusing Globe	IV	75	0.8
HEAVY TO HEAVIEST TRAFFIC (1200 & UP VEH PER HR.) (MEDIUM PEDESTRIAN)  	79-R (#4110 Refr.)	III	120	1.16
HEAVY TO HEAVIEST TRAFFIC (1200 & UP VEH PER HR.) (HEAVY PEDESTRIAN)  	79-AD 15,000 Lumen #232 Diffusing Globe	IV	125	1.2
	79-AD 16,000L. Merc'y #232 Diffusing Globe	IV	115	1.2

Note:

(1) Above foot-candle values based on *10%* pavement reflectance, such as very light asphalt or oil-stained concrete. With *20%* pavement reflectance, above values may be *reduced* 25%; with *5%* reflectance, these values should be *increased* 50%. (Especially applicable on streets having *less* than 0.8 foot-candle.)

(2) Refer to Tables IV and V in IES *Recommended Practice of Street & Highway Light—1945 Text* for variation to above foot-candle averages due to varying *pedestrian traffic*; and for other typical permissible foot-candle, lamp-size, pavement-width, spacing combinations.

(3) Retail business streets should receive *at least* same illumination levels specified for traffic streets carrying same *vehicular* traffic, with usually medium or heavy *pedestrian* traffic.

(4) Vehicular traffic volume is "Maximum night hour, both directions."

(5) Data under heading "Most Effective G-E Equipment" was prepared by G-E engineers, and IES approval is not implied.

(6) Copies of IES *Recommended Practice of Street & Highway Lighting—1945* can be obtained from the Illuminating Engineering Society, 51 Madison Ave., New York City.

GENERAL ELECTRIC

SCHENECTADY, N. Y.

LIGHTING RECOMMENDATIONS FOR SPORTS AND RECREATION FACILITIES

Sport	No. of Poles	Mounting Height (In Feet)	Floodlights			Kw Load at		Application Drawing for Bulletin
			Number	Type	Lamp	Rated Voltage	10 per cent Overvoltage	
Badminton	2	20	4	L-49	500	2.0		M-25395-N
*Baseball								
Municipal—Semi-pro	8	80	120	L-69	1500		209.0	M-25452Q & Q-1
Minimum	8	60–80	100	L-69	1500		174.0	M-25452E
*Basketball	4	30	8	L-69	1500	12.0		M-25415-V
Boxing or Wrestling Ring	4	18	8	L-43	1000	8.0		M-25415-R
Bowling Greens	8	30	12	L-43	1000		13.9	M-25376-V
Croquet	4	20	4	L-49	300	1.2		M-25415-U
*Football								
Class A	8	60–80	128	L-69	1500		215.0	GET-1374
Class B	8	60–80	96	L-69	1500		167.0	
Class C	8	60–80	72	L-69	1500		125 0	
Six-Man	6	40–60	36	L-69	1500		62.7	
*Golf Driving								
One 30-ft pole for each 50 ft of tee with the following per pole:			3	L-69	1500			M-25395-O
			3	L-31†	1000‡			
Handball—Playground								
1 pole for 2 courts with the following per pole:		25	2	L-69	1500			M-25452-U
Tournament Play								
1 pole per court with the following per pole:		30	2	L-69	1500			M-25452-V
*Hockey Rink	8	40	16	L-69	1500			M-25376-U
			4	L-43*	1000		32.5	
*Horseshoes								
1 to 3 Courts	2	20	2	L-43*	750	1.5		M-25415-L
4 to 8 Courts	4	20	4	L-43*	750	3.0		
Shooting—Archery								
*30-ft Range	1	10	1	L-29†	250‡	0.25		M-25452-Y
*50-ft Range	1	10	1	L-30†	500‡	0.50		
*75-100-ft Range	1	10	1	L-31†	1000‡	1.00		
Trap	2	20	8	L-43	1000		9.3	M-25368-S
Skeet	2	25	10	L-43*	1000		11.6	M-25415-O&P
Shuffleboard								
1 to 3 Courts	2	20	2	L-43*	750	1.5		M-25376-X
4 to 8 Courts	4	20	4	L-43*	1000	4.0		
*Soccer	8	40–60	40	L-69	1500	60.0	69.5	M-25484-D
*Softball								
Class A	8	40–60	24	L-69	1500	36.0	42.8	GEA-2918-C
Class B	8	40–60	18	L-69	1500	27.0	31.3	
Class C	6	40	14	L-69	1500	21.0	24.4	
*Swimming Pools								
Underwater			See text section 12					
Overhead	4–6	25–30	6–8	L-69	1500			GEA-2909-A
*Tennis—Playground								
One Court	4	30	8	L-69	1000	8.0	9.3	GEA-3310-A
Two Courts	4	30	8	L-69	1500	12.0	13.9	
*Tennis—Tournament								
One Court	8	30	12	L-69	1000	12.0	13.9	GEA-3310-A
Two Courts	8	30	12	L-69	1500	18.0	20.9	
Volley Ball	2	20–25	4	L-49	500	2.0		M-25452-Z

* Denotes general-purpose floodlight. † Denotes heavy-duty floodlight. All floodlights otherwise are sports type. ‡ Denotes floodlighting service lamp. All lamps otherwise are general service.

Layout in accordance with *NEMA Recommended Practice.*

CHEMICAL DEPARTMENT

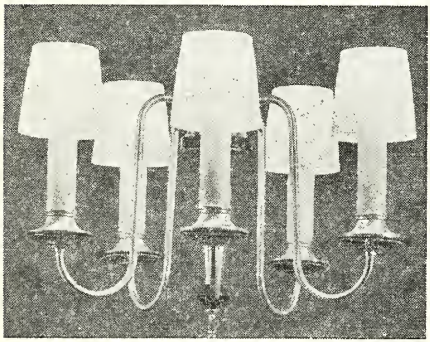
GENERAL ELECTRIC

Pittsfield, Mass.

SALES OFFICES

Atlanta, Ga.	187 Spring Street N.W.
Boston 1, Mass.	140 Federal Street
Chicago 7, Ill.	840 So. Canal Street
Cleveland 4, Ohio	4966 Woodland Avenue
Detroit 2, Mich.	700 Antoinette Street
Los Angeles 54, Cal.	212 No. Vignes Street
Meriden, Conn.	34 Cambridge Street
Newark 2, N. J.	744 Broad Street
New York 22, N. Y.	570 Lexington Avenue
Philadelphia 2, Pa.	1405 Locust Street
Pittsburgh 22, Pa.	535 Smithfield Street
Pittsfield, Mass.	1 Plastics Avenue
Providence 3, R. I.	111 Westminster Street
Springfield 3, Mass.	1387 Main Street
St. Louis 8, Mo.	3615 Olive Street

G-E PLASTICS LIGHTING DIFFUSERS—STANDARD LINE



G-E plastics lighting diffusers for candlelight modernization.

G-E plastics lighting diffusers for better lighting are manufactured from urea plastic compounds—Plaskon No. 8070 and Beetle No. 515-10 (see the Plaskon insert, page M-95, for urea compound lighting characteristics). The standard line consists of eleven types of diffusers which are used for two purposes (1) to serve as replacement shades and reflectors on lamps designed to utilize diffusers of this type. (2) to modernize out-of-date fixtures and lamps at low cost. These diffusers are attractively designed, have uniform light characteristics and accurate dimensions. Then, too, they are lightweight and reduce glare by diffusing light sources.

Illustrated is one type of G-E plastics lighting diffuser in use. For a complete description of the 11 available types for a wide variety of uses, write for the bulletin, "G-E Plastics For Light Conditioning".

G-E PLASTICS LIGHTING DIFFUSERS—CUSTOM LINE

The General Electric Company molds urea lighting diffusers to lamp and fixture manufacturer's specifications. A complete mold making department is maintained and an experienced staff of plastics designers is ready to help with styling.

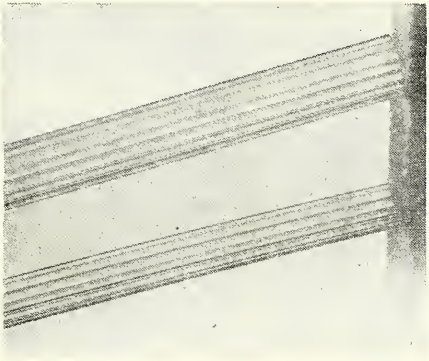
Illumination data from test by General Electric Co. Testing Laboratories.

CHEMICAL DEPARTMENT

GENERAL ELECTRIC

Pittsfield, Mass.

G-E PLASTICS EXTRUDED LIGHTING SHAPES



General Electric will extrude transparent plastics shapes for lighting applications to custom specifications. G.E. will build the molds and engineer the job from start to finish. Lighting consultants and designers are also part of this G-E plastics service.

An extruded side of a fluorescent lighting fixture made from polystyrene. Flutes in the shape of lenses aid in light diffusion.

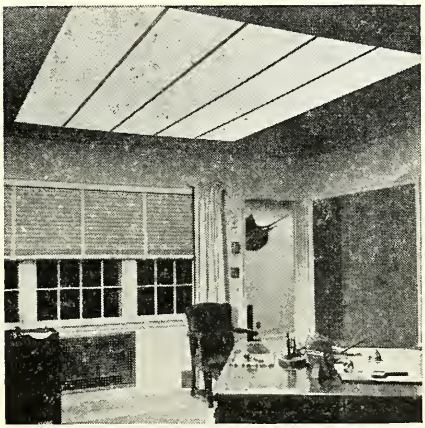
G-E PLASTICS INJECTION-MOLDED LIGHTING COMPONENTS

Transparent thermoplastic compounds are injection molded for fluorescent lighting applications by General Electric who assume complete responsibility for the production of your components—design the part, engineer the job, build the molds and do the manufacturing.



End-plates for a fluorescent lighting fixture injection molded from polystyrene.

G-E LAMINATED PLASTICS TRANSLUCENT SHEETS



A lighting application featuring G-E translucent sheets in the office of W. S. Leffler, Noroton, Conn.

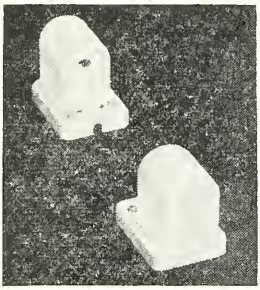
This translucent material is produced in flat or formed sheets and is used primarily in fluorescent lighting applications. The advantages of this thermosetting laminate for lighting uses result from its lightweight, flexibility and high light transmission. For example, a sheet .020 inches in thickness has 70% light transmission, 18% reflection and 12% absorption. It remains colorfast to a high degree in both indoor and outdoor applications. It is produced in thicknesses from .020″ to .060″ in 18″ by 108″ sheets. Special sizes can be produced up to 36″ by 72″.

GENERAL ELECTRIC

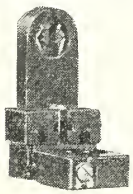
APPLIANCE AND MERCHANDISE DEPARTMENT

Bridgeport, Connecticut

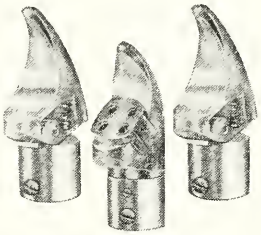
Accessories for Fluorescent Lighting Equipment



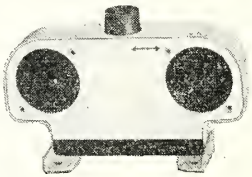
G-E Slimline Lampholders — These lampholders are specially designed to provide a simple and convenient means of mounting all General Electric Slimline lamps. For lamps of the single-pin type, they accommodate T8 and T6 Slimline lamps. One receptacle for the lamp pin is spring-backed. When pushed in, it affords clearance at the other end for the lamp to slip into the opposite lampholder. The other receptacle has two spring contacts which open the transformer primary when the lamp is removed.



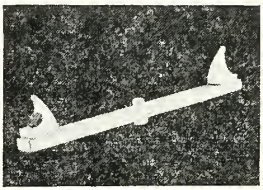
G-E Rotating Lock Lampholders — These lampholders provide positive electric contact, and hold lamps firmly in place. They are available in black or white Textolite.*



G-E Individual Circline Lampholders and Tension Supports — These lampholders are available for those who wish extra flexibility in designing. One three-support set is comprised of a single lampholder and two spring-tension supports. All are made of plastic, and have die-cast hubs with $\frac{1}{8}$-inch pipe threads. Lampholder is furnished with leads of various lengths.



G-E Twin Turret Lampholders — These lampholders are designed for industrial lighting fixtures where sturdy mounting for standard 40-watt fluorescent lamps is required. They have a metal housing, and are built to withstand hard usage. Insertion of lamp is quickly possible by depressing either contact plate of holder with lamp end.



G-E Circline Lampholders — These lampholders provide a simple method of mounting and connecting Circline lamps to portable lamps. One-piece unit consists of an enameled steel channel with plastic lampholder at one end and a spring-loaded tension support at opposite end. Available either with or without built-in manual starter switch.



G-E Standard Starters and Watch Dog* Starters —There are all types and sizes of starters in the General Electric line. FS-2 standard starters for 15- and 20-watt F lamps to FS-64 starters for 65-watt and 100-watt F lamps. FS-20 Watch Dog starters for 15- and 20-watt F lamps to FS-100 starters for 100-watt F lamps. Watch Dog starters provide precision starting for maximum lamp life. They eliminate blinking and flickering of dying lamps by cutting the lamp out of the circuit.

*Trade-mark Reg. U. S. Pat. Off.

For detailed information, write to Section xxx, Appliance and Merchandise Department, General Electric Company, Bridgeport 2, Conn.

GENERAL ELECTRIC

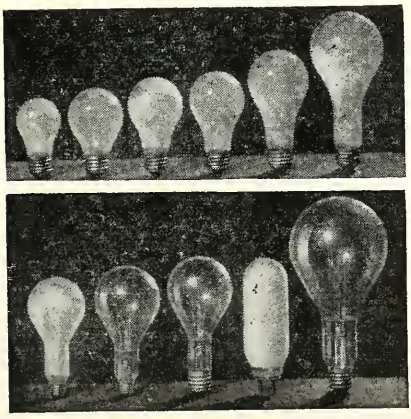
LAMP DEPARTMENT–NELA PARK, CLEVELAND 12, OHIO

TECHNICAL DATA on standard lamps, special lamps and their applications, are as near as your mail or telephone. A call to any of the Sales District offices below will bring you up-to-date, ready-to-use facts and information . . . and, perhaps, the practical idea you've been looking for.

Sales District	Street Address	Telephone No.
ATLANTA 3, GA.	187 Spring St., N. W.	WAlnut 9767
BOSTON 10, MASS.	50 High Street	HANcock 1680
BUFFALO 2, N. Y.	901 Genesee Building	CLeveland 3400
CHARLOTTE 2, N. C.	1117 Johnston Building	4-8614
CHICAGO 4, ILL.	231 So. La Salle Street	HARrison 5430
CINCINNATI 2, OHIO	215 W. Third Street	PArkway 3431
CLEVELAND 14, OHIO	1320 Williamson Building	CHerry 1010
DALLAS 2, TEXAS	1801 North Lamar Street	Central 7711
DENVER 2, COLO.	1863 Wazee Street	MAin 6141
DETROIT 26, MICH.	1400 Book Tower	CHerry 6910
N. KANSAS CITY 16, MO.	200–210 E. 16th Avenue	NOrclay 3568
LOS ANGELES 13, CALIF.	601 West Fifth Street	MIchigan 8851
MINNEAPOLIS 13, MINN.	500 Stinson Boulevard	GRanville 7286
NEW YORK 22, N. Y.	570 Lexington Avenue	WIckersham 2-6300
OAKLAND 7, CALIF.	1614 Campbell Street	HIghgate 7340
PHILADELPHIA 2, PA.	1405 Locust Street	KIngsley 5-3336
PITTSBURGH 22, PA.	535 Smithfield Street	GRant 3272
PORTLAND 9, ORE.	1238 N. W. Glisan Street	BEacon 2101
ST. LOUIS 1, MO.	710 North Twelfth Boulevard	CHestnut 8920

GENERAL ELECTRIC MAKES lamps for every lighting service. In fact, there are over 9,000 different types and sizes of G.E. Lamps, of which only a few can be shown on these pages. G-E Lamp Research is continually at work to develop new and better lamps. Its constant aim is to make G-E Lamps *STAY BRIGHTER LONGER.*

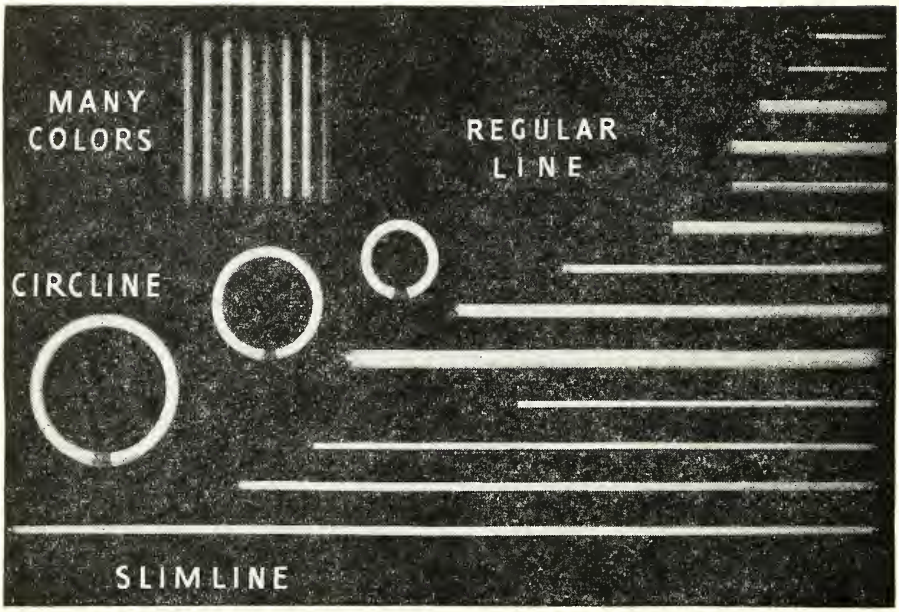
General Electric does not make fixtures but manufactures a complete line of light sources and works in cooperation with fixture manufacturers to help them utilize these sources most efficiently.



G-E GENERAL PURPOSE FILAMENT LAMPS

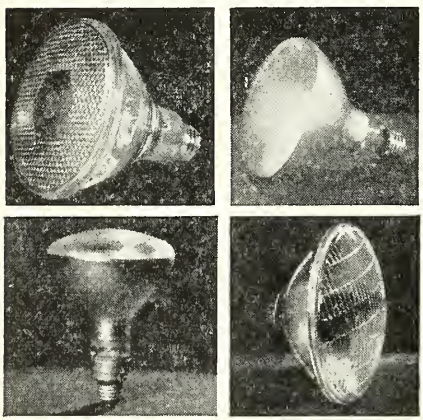
G-E tungsten filament lamps are available in sizes from 6 to 1500-watts. Widest selection is in Inside-Frosted Lamps. Clear and Inside White Bowl finishes may be obtained for specialized uses, but not in all types and sizes. Bases are Candelabra, Intermediate, Medium or Mogul screw base. Bi-Post base is an alternative in the 750 and 1000-watt sizes. In general, G-E filament lamps are made for operation on 115, 120 and 125-volt circuits. Others (25 to 1000-watts) available for 230 and 250-volt circuits and also (15 to 100-watts) for low voltage country home service.

GENERAL ELECTRIC



G-E FLUORESCENT LAMPS

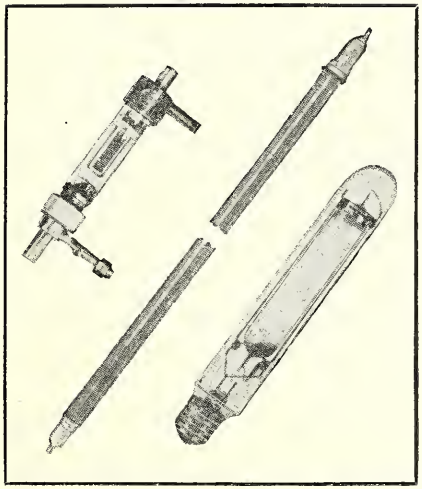
The standard G-E line includes wattages from 6 to 100-watts, in white and colors. G-E SLIMLINE lamps range from 42 to 96 inches in length. Designed to operate at current values from 100 to 200 milliamperes. Start instantly, without starters. G-E CIRCLINE lamps will be made in three diameters—8½, 12 and 16 inches, as soon as conditions permit.



SEALED REFLECTOR LAMPS

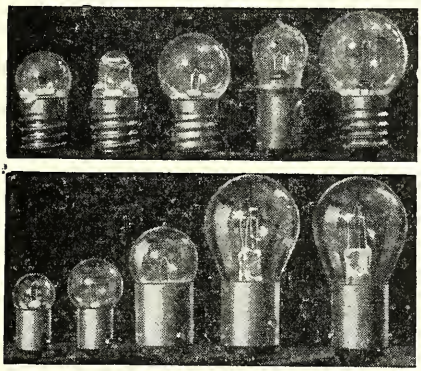
These include a broad group of G-E Lamps with built-in reflectors—an integral part of the bulb. Hermetic seal excludes moisture, air and dirt, Reflector and Projector Spot and Flood Lamps, Sealed Beam Headlamps and Infra-Red Drying Lamps are included in this versatile type.

GENERAL ELECTRIC



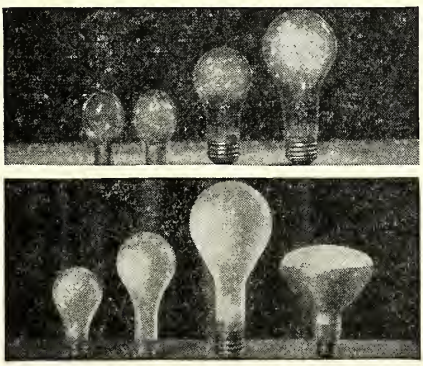
MERCURY LAMPS

"High-efficiency" sums up the features of General Electric's MERCURY Lamps. Widely used for industrial lighting in high and medium-high bays, these arc-source lamps are made in 100, 250, 400 and 3,000-watt sizes. The 1,000-watt (water-cooled) lamp finds many uses in search-lights, studios, photo-engraving.



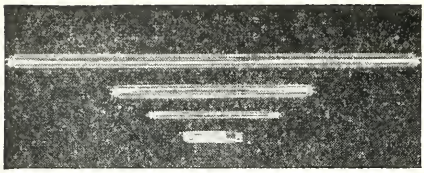
MINIATURE LAMPS

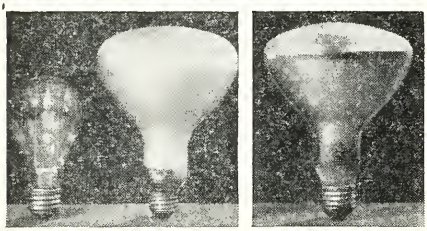
General Electric's complete line includes a wide selection of miniature lamp types. Shown here are several representative types, including flashlight, hand lantern and bicycle lamps; glow lamps, indicator lamps and miniature automotive lamps. Other types and sizes available for both general and specialized uses.



PHOTOGRAPHIC LAMPS

All types and sizes for nearly every kind of photographic work. G-E Photo*flash* Lamps give a split-second, high-intensity flash. G-E Photo*flood* Lamps provide a constant light source for portrait and still-life pictures. G-E Projection Lamps are made from 75 to 1500 watts for accurate concentrated light in motion picture and stereopticon service.



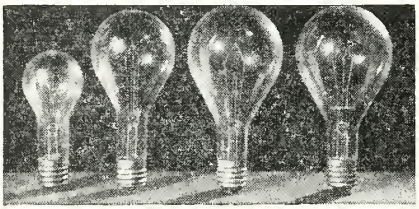


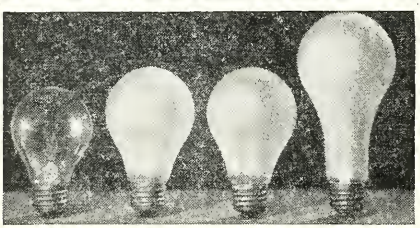
HEALTH LAMPS

G-E Germicidal Lamps supply short-wave ultraviolet energy which kills germs. Made in four sizes—4, 8, 15 and 30 watts. Must be used in properly designed and installed fixtures to keep radiation away from eyes and skin.

G-E Sunlamps—S-4 and RS—provide ultraviolet energy that produces Vitamin D and has same tanning effect as mid-summer sun.

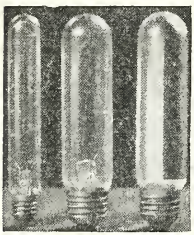
G-E Heat Lamps—supply soothing, penetrating infra-red heat for relief of aches and pains. Also for wide variety of drying uses.

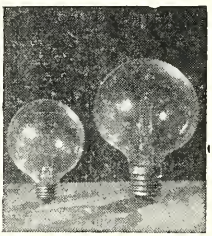


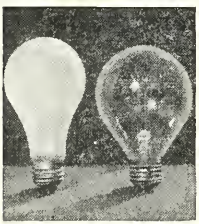


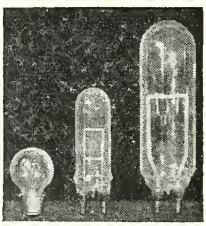
STREET, RAILWAY LAMPS

Full range of lamps for street and railway lighting. For street lighting, lamps are available for both series and multiple service. For railway service, G-E Headlamps operate in series with four lamps of corresponding wattage and voltage. Lamps for street car lighting operate similarly, five-in-series.









SPECIAL PURPOSE LAMPS

Over 9,000 different G-E Lamps are made to fit every type of specialized application. Available are G-E Lamps for sign lighting, spot lighting and flood lighting; showcases, railroad, aircraft, and airports; vibration and rough service. Full data upon request.

GENERAL ELECTRIC SUPPLY CORPORATION

General Offices, Bridgeport, Connecticut

Gesco, through its nation-wide group of offices and warehouses provides a quick, dependable source for the products of America's leading Electrical Manufacturers . . . plus an advisory service to Contractors, Engineers, and Architects through its staff of Specialists, trained in the most modern and efficient application of lighting, power apparatus and other electrical materials. Call the Gesco house most convenient to you.

112 OFFICES AND WAREHOUSES . . . A NATION-WIDE SERVICE

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Fort Wayne
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Muncie

IOWA
Des Moines

KANSAS
Wichita

KENTUCKY
Harlan
Lexington
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LOUISIANA
New Orleans
Shreveport

MAINE
Bangor
Portland

MARYLAND
Baltimore

MASSACHUSETTS
Boston
Springfield
Worcester

MICHIGAN
Detroit
Grand Rapids
Kalamazoo
Lansing
Saginaw

MINNESOTA
Duluth
Minneapolis
St. Paul

MISSISSIPPI
Jackson

MISSOURI
Joplin
Kansas City
St. Louis
Springfield

MONTANA
Billings
Butte

NEBRASKA
Omaha

NEW HAMPSHIRE
Manchester

NEW JERSEY
Jersey City
Newark
Paterson

NEW MEXICO
Albuquerque

NEW YORK
Brooklyn
Buffalo
New York
Niagara Falls
Rochester

NORTH CAROLINA
Charlotte
Raleigh

OHIO
Akron
Canton
Cincinnati
Cleveland
Columbus
Dayton
Toledo
Youngstown

OKLAHOMA
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Portland

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Scranton
Wilkes-Barre

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Providence

TENNESSEE
Chattanooga
Knoxville
Memphis
Nashville

TEXAS
Abilene
Amarillo
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Corpus Christi
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El Paso
Fort Worth
Houston
Lubbock
San Antonio
Waco

UTAH
Salt Lake City

VIRGINIA
Norfolk
Richmond
Roanoke

WASHINGTON
Seattle
Spokane
Tacoma

WEST VIRGINIA
Wheeling

WISCONSIN
Appleton
La Crosse
Milwaukee

GENERAL LUMINESCENT CORPORATION

732 South Federal Street, Chicago 5, Illinois

*COLOVOLT

Cold Cathode, lamps and fixtures for commercial and industrial installations.

COLOVOLT cold cathode fluorescent lamps, designed to operate on standard 120 m. a. 750 volt ballasts, are 93″ long and 25 MM. in diameter. These lamps are manufactured in four standard colors: 3500° White; Soft White; Daylight and 4500° White. Table one (1) furnishes engineering data for operation of two COLOVOLT lamps on a two-tube brick type, cold cathode ballast. The resultant light from a system of two or more lamps operating on duo-ballasts is essentially free of stroboscopic effect. Standard COLOVOLT ballasts are designed to operate from a 118 volt line but COLOVOLT lamps will operate from a 230 or 440 volt line when properly designed ballasts, which can be made available for that purpose, are used. Though designed for average secondary voltage operation of 420 volts, COLOVOLT lamps will operate effectively in high voltage series circuits. Secondary voltages up to 15,000 volts may be used if the proper number of lamps is placed in the series circuit. In a standard installation, primary voltage variations from 105 to 125 volts will not cause any lamp failure or flicker. However, the light output will be affected and in occasional cases there may be a difference in brightness between the capacitive and the inductive lamp when the primary voltage falls below 108 volts.

COLOVOLT lamps are highly practical for continuous line lighting because they are long light sources (standard length 93″ plus or minus $\frac{1}{8}$″) and because the number of sockets and connections needed are substantially reduced.

Every COLOVOLT lamp is guaranteed for one year except for failure due to breakage.

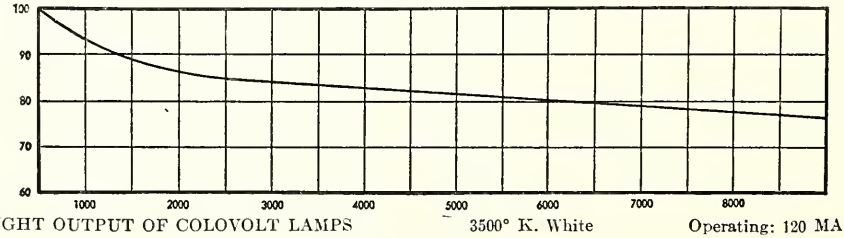
Table two (2) gives a curve of light output during lamp life.

Data given in the following tables has been compiled in the laboratories of General Luminescent Corporation at Chicago, Illinois.

ENGINEERING DATA

DETAILS	TWO COLOVOLT 3500° K. WHITE LAMPS ON ONE COLD CATHODE BALLAST (93 INCH, 25-MM. LAMPS)
Total lumen output per lamp (average)	2400
Average lamp life	10,000 hours
Lumens per watt of lamp	57.1
Lumens per watt including reactor losses	44.0
Overall power factor (2 lamps operating on 1 duo ballast)	98%
Primary voltage	118
Primary amps (2 lamps operating on 1 duo ballast)	0.93
Primary wattage (2 lamps operating on 1 duo ballast)	109 watts
Primary V. A. (2 lamps operating on 1 duo ballast)	109.7
M. A. Per lamp (average)	120
Average lamp voltage	420
Average lamp V. A.	50.4
Average lamp wattage	42

TABLE 1



LIGHT OUTPUT OF COLOVOLT LAMPS 3500° K. White Operating: 120 MA

BURNING HOURS

TABLE 2

Since fixture specifications, sizes and fittings change from time to time, fixture data has not been included on this page. We will be glad to furnish complete information on all available fixtures to interested parties.

* Trade Mark Reg. U.S. Patent Offices.

GILL GLASS AND FIXTURE CO.

Philadelphia 34, Pa.

Glass-Metal Reflector Combinations for "Certified" Lamps



OPAL GLASS WITH WHITE ENAMELED REFLECTORS

Type	Top Diameter Inches	Overall Length Inches	For Lamp Sizes Watts	Specified "D" Value* Footcandles
C	7½	8¾	50, 100, 150	4.5
B	8	7¼	50, 100, 150	5.5
A	10	8	100, 200, 300	10.0

* Normal illumination 45° from nadir five feet from source.

Certified by Electrical Testing Laboratories, Inc.

GLEASON-TIEBOUT GLASS COMPANY

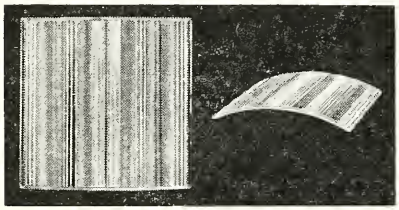
Main Office and Plant
59-50 54th Street, Maspeth, N. Y.

Mailing Address:
P. O. Box 132—Station "G"
Brooklyn 22, N. Y.

New York Office and Showroom
200 Fifth Avenue, New York 10, N. Y.

Sales Offices: Los Angeles, San Francisco, Seattle, Denver, Chicago, Detroit, Richmond, Va., Greensboro, N. C.

Blown and Pressed Lighting Glassware for Commercial, Industrial, Residential, Technical and Street Lighting.
Lenses, Globes, Bowls, Balls, Cylinders, Shades, Reflectors, Torchiere Glass.
Clear glass, Opal, Cased, Dual Opacity, Ivory, Colored glasses, Special densities.
Etched, Decorated, Cut and Enameled Ware. Special Mould Work.



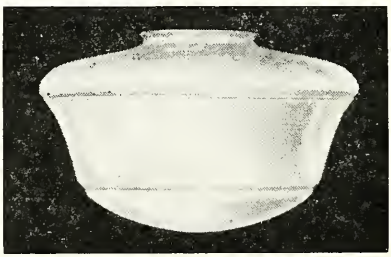
12359

Curved Fluorescent Plate. 12″ wide, 12″ long.
Fresnel detail. Used end to end. For 4-tube fixtures. Clear or Satin Finish.

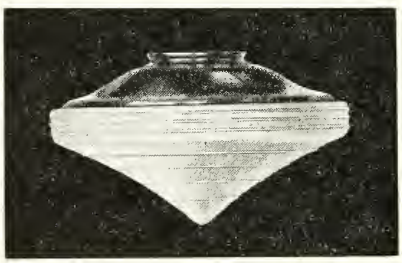
The plates are designed to offset loss of light thru absorption. E.T.L. Reports 155985 and 155986 indicate that plates used with properly designed equipment accomplish this, affording diffused lighting while producing the same total of footcandles on working plane as the same fixture produces with bare tubes.

11290

Enclosing globe for diffused lighting. Made in all-white single-layer Silvaglo glass.
ETL Report 48617 average light output six globes—83.5%.



Standard School Globe City of Greater New York.
Approved for U. S. Treasury Department work. Sizes—18″, 16″, 14″, 12″, 10″, 9″, 8″.



12176

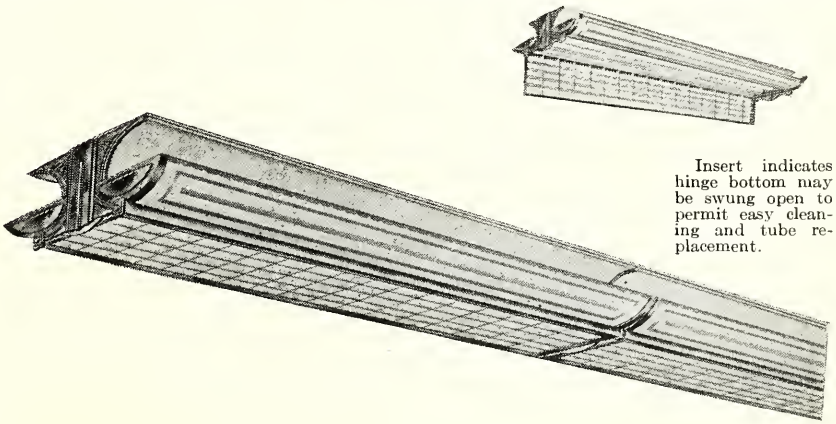
L. S. B. Glass for enclosed indirect lighting. According to ETL Reports 142007, 142244 and 150863 for L. S. B. glass globes, light upward approximately 80% with light output ranging from 75% to 80% with surface brightness under 2 cp per sq. in.

Recommended for hospitals, schools and wherever eye comfort is of prime consideration.
12176 globe made 20″, 18″, 16″, 14″, 12″, 9″.
L. S. B. glass Mfr. licensed under U. S. Pat. 1778305.

GLOBE LIGHTING PRODUCTS COMPANY

East Coast Plant—7th Avenue and 12th Street, Brooklyn, N. Y.
West Coast Plant—21st and Main Street, Los Angeles
New York Showrooms—16 East 40th Street

Specified for continuous lighting of industrial . . . commercial . . . public interiors for over quarter-of-a-century. . . . FLUROLUME—an exclusive product of Globe



Insert indicates hinge bottom may be swung open to permit easy cleaning and tube replacement.

Flurolumes may be ganged to provide continuous fluorescent lighting over large areas for work of a close or detailed nature. Body reflectors are specially processed of "Glarex glass" and finished in durable baked white enamel. Louvers of the lower section are spaced to provide controlled lighting. Glass side panels are ceramic treated for permanence of design and color . . . may be washed, cleaned without fading or erasure. Flurolumes are designed and crafted entirely within Globe's own plants.

ILLUMINATION CHART

FIXTURE	FT. CANDLES		SQUARE FEET PER FIXTURE								
			LARGE ROOM			MEDIUM ROOM			SMALL ROOM		
	INITIAL	MAINT.	LIGHT	MED.	DARK	LIGHT	MED.	DARK	LIGHT	MED.	DARK
KG.1288-40	10	7	540	450	400	460	390	330	350	280	240
	20	14	270	225	200	230	195	165	175	140	120
	30	21	180	150	135	155	130	110	120	95	80
	50	35	110	90	80	90	80	65	70	55	50
	70	49	77	64	57	66	55	47	50	39	34
	100	70	54	45	40	46	39	33	35	28	24
ROOM INDEX			B	B	B	E	E	E	J	J	J
COEF. OF UTILIZATION			.59	.49	.43	.50	.42	.36	.38	.30	.26

INSTRUCTIONS

Obtain from the table the square feet per fixture for the given room size, finish and desired level of illumination. To determine the number of fixtures required, divide the square feet per fixture (obtained from the table) into the floor area.

EXAMPLE: Find the number of fixtures required to obtain 50 foot candles initially in a large sized room (50′ x 100′) with a light finish, mounting height 12′. From the table the required sq. ft. per fixture is 110. The total number of fixtures required is 50 x 100/110 = 45.

KG1286-40

BODY DIMENSIONS Number	Lts.	Watts	Width	Height	Body Length	Length Overall	Ship Wt. (app.)
KG1288-40	4	40	15″	7½″	49″	Flush cont.	50 lbs.
KG1286-40	4	40	15″	7½″	49″	Flush	50 lbs.

Illumination Data from Tests by Electrical Testing Laboratories, Inc.

GOODRICH ELECTRIC COMPANY

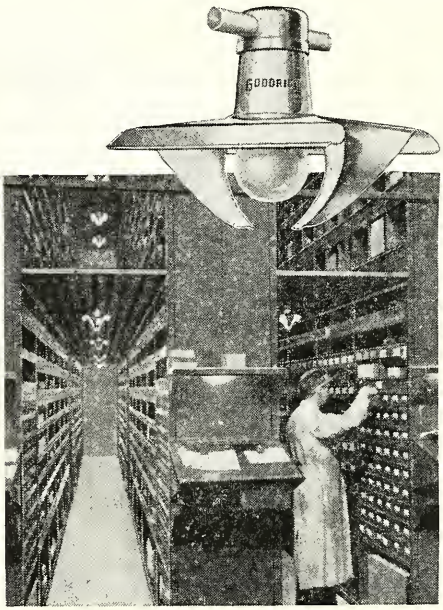
4600 Belle Plaine Avenue

Chicago 41, Illinois

Industrial lighting equipment—including a complete line of standard and special purpose fixtures. Also a complete line of floodlights, sign reflectors and special lighting equipment for indoor and outdoor uses.

THE STOCKLITE

Finished in vitreous fired porcelain enamel.



A typical Stocklite installation. Complete information is available in Bulletin 91.

The Goodrich Stocklite is designed for illuminating shelves and bins in narrow stockroom aisles.

Mounted even with the top of shelves or bins, this reflector directs maximum light to the shelves to provide uniform illumination from top to bottom row. Curved V-shaped flanges cut off aisle glare, directing still more light to build up intensities in bin interiors.

The Goodrich Separable hood permits instant removal for easy cleaning.

The Stocklite is available with pendant, right-angle, or feed-thru hood, tapped for ½-inch conduit; or with hood that fits 4-inch standard outlet-box. Width 8½ inches; length, 12¼ inches; height varies from 8⅝ inches to 11¼ inches to accommodate lamp sizes from 60 to 200 watts. Furnished with keyless or pull-chain socket.

GRAYBAR ELECTRIC COMPANY

Executive offices: Graybar Building, New York 17, N. Y.



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Practical Assistance in Obtaining Information and Equipment

THIS HANDBOOK contains all the engineering information you need to check existing lighting installations against the best recommended practice—to decide the best type of light source—and to lay out a lighting system.

Graybar Electric Company, distributor of 60,000 electrical products, can supply all the commercial information you need—such as cost estimates on various types of fixtures, delivery dates, and lighting curves of specific units.

Lighting Units for Every Purpose

Whatever your requirements, Graybar can impartially recommend the exact lighting equipment for your particular needs from the most complete selection of lamps and lighting units available from any one source.

The lighting equipment which Graybar distributes includes incandescent, fluorescent, and mercury-vapor fixtures, made by leading manufacturers; G-E lamps; lighting transformers, ballasts, switches, wiring materials and supplies.

For many years, Graybar Lighting Specialists have been helping to provide the right answers to commercial, industrial, and product lighting problems. The services of these experienced men are available through any of the Graybar offices or warehouses at the locations listed above. 4745

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Phone: Kenmore 2042

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Phone: Harrison 2994

Cincinnati, Ohio
634 Glenway
Phone: Valley 7086

Cleveland, Ohio
801 Caxton Bldg.
Phone: Su 5319

Dallas, Texas
3131 Grove St.,
Phone: Da-4471

Denver, Colo.
Alex Hibbard Co
1863 Wazee St.,
Phone: Keystone 5319

Detroit, Mich.
22555 Gregory Ave.,
Phone: Dearborn 8713

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Phone: Prospect 1717

Memphis, Tenn.
3874 Faxon Ave.,
Phone: 4/2170

New York City, N. Y.
Room 2268, 50 Church St.
Phone: Barclay 7-9073

Philadelphia, Pa.
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Phone: Lombard 3-4669

Pittsburgh, Pa.
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Rochester, N. Y.
P.O. Box 166
Phone: Canandaigua 1001 M

St. Paul, Minn.
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Phone: Emerson 5914

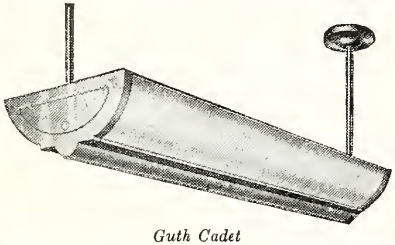
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GUTH FLUORESCENTS are wired High Power Factor with highest quality accessories of reputable manufacturers. Reflectors are engineered to accomplish specific lighting results. Listed by Underwriters' Laboratories, Inc. Incandescent and Germicidal Lighting Units and Custom-built Luminaires are also available. Many patents and trade-marks are applicable to the following listings.

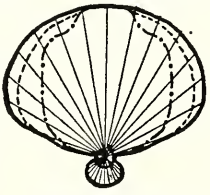


Guth Cadet

M3050	2-40W	48½″ × 10½″ × 5½″	40 lbs.
M3051	2-100W	60⅛″ × 10½″ × 5½″	60 lbs.

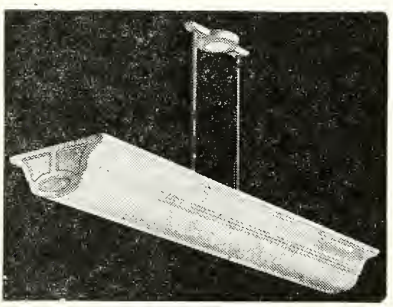
Note: Guth M3337 Single-Stem Hangers (26″ long) are extra.

The CADET



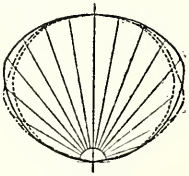
Light Curve—Cadet

Luminous Indirect Luminaire. Sides are white translucent glass. Die-panelled ends and reinforcing steel "spine", finished 300° White Enamel. K.O.'s in ends for wiring and locking in continuous rows. Efficiencies: 2-40W, 83% (72% up and 11% downlight); 2-100W, 75%, (64% up and 11% downlight). Maintenance Factor, both types, .65.



Guth Fluo-Indirect

The FLUO-INDIRECT

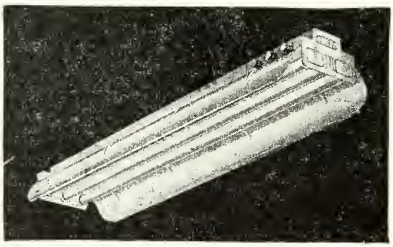


Light Curve Fluo-Indirect

Totally Indirect Luminaire. Two-section steel body, bottom half removable. Ornamented steel ends and body finished 300° Pale Ivory. K.O.'s in ends for wiring and locking in rows. Efficiencies: 2-40W, 78%; 4-40W, 70%; and 2-100W, 72%. Maintenance Factor, .60.

M2320	2-100W	60⅛″ × 12¼″ × 5½″	55 lbs.
M2321	2-40W	48⅛″ × 12¼″ × 5½″	38 lbs.
M2325	4-40W	48⅛″ × 12¼″ × 5½″	45 lbs.

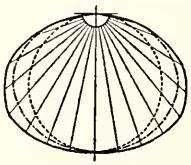
Note: Hangers extra. Use M3333 Double-Stem, or M3337, Single Stem.



Guth Mazelite

M3075	2-40W	48⅛″ × 13⅛″ × 6½″	25 lbs.
M3076	3-40W	48⅛″ × 13⅛″ × 6½″	29 lbs.
M3077	2-100W	60⅛″ × 16⅛″ × 7½″	39 lbs.

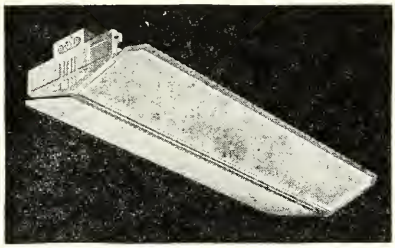
The MAZELITE



Light Curve-Mazelite

Direct type Industrial Luminaire. Bumpproof ends, side-of-channel starters, grooved for sliding hangers, heavy gauge steel-construction. Exterior finished Industrial Gray; Reflector, 300° White Enamel. K.O.'s in ends for wiring and locking in rows. Lamp shielding 15° from horizontal in 2 and 3-40W, and 14% in 2-100W. Efficiencies, 2-40W, 85%; 3-40W, 82%; 2-100W, 81%. Maintenance Factor: .70.

Light Distribution Curves from test in company laboratories Performance Data from tests by Electrical Testing Laboratories



Guth Aristolite

M3030	2-40W	48⅛″ × 12½″ × 6½″	36 lbs.
M3031	3-40W	48⅛″ × 12½″ × 6½″	39 lbs.
M3032	4-40W	48⅛″ × 17½″ × 6½″	50 lbs.

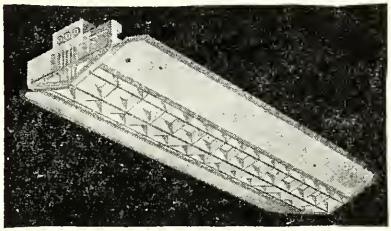
Note: For suspending from ceiling, use Guth M3333 Hanger.

The ARISTOLITE



Light Curve Aristolite

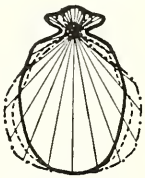
Semi-Direct Luminaire. Diffusers are configurated glass (86.4% T.F.) attached with "sliding groove" and hinge. Reflectors, panelled die-cut ends and channels, finished 300° White Enamel. K.O.'s in ends for wiring and locking in continuous rows. Efficiency: 2-40W, 79.5%, (61% down-light, 18.5% up-light); 3-40W, 75.5%, (61.5% down and 14% up-light); 4-40W, 73%, (54.5% down and 18.5% up-light). Maintenance Factor: .65.



Guth Eggcrate Aristolite

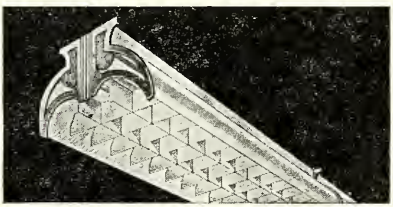
M3040	2-40W	48⅛″ × 12½″ × 7″	46 lbs.
M3041	3-40W	48⅛″ × 12½″ × 7″	49 lbs.
M3042	4-40W	48⅛″ × 17½″ × 7″	60 lbs.

EGGCRATE ARISTOLITE



Light Curve Eggcrate Aristolite

Companion design of unit above. Eggcrates finished 300° White Enamel and seat in "step-locks" in ends. Glass Panels, keyed in sliding grooves. Efficiency: 68%, (48% down and 20% up-light). Maintenance Factor: .65.

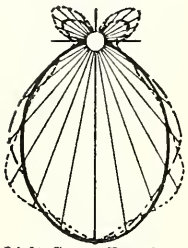


Guth Futurliter

M2500	2-40W	48⅜″ × 12⅛″ × 8⅛″	39 lbs.
M2501	3-40W	48⅜″ × 12⅛″ × 8⅛″	43 lbs.

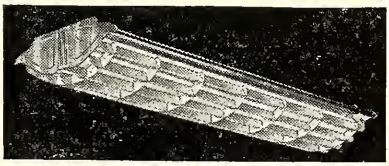
Note: In continuous runs, ¼″ saved when end flutes are removed. Can be suspended on Guth Hangers.

The FUTURLITER



Light Curve, Futurliter with Eggcrates

Shielded-Direct Luminaire. Eggcrates seat in "step-locks" and shield lamps at normal seeing angles. Finished in 300° White. Ends trimmed with polished aluminum flutings which are removed for continuous rows. Knock-Outs under flutings for wiring and locking. Efficiency: 2-40W, 75.5%, (55.5% down and 20% up-light); 3-40W, 69%, (54.5% down and 14.5% up-light). Maintenance Factor: .70.

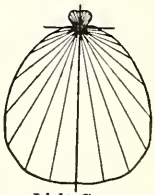


Guth Eggcrate Trucolite

M3150	4-40W	48⅜″ x 16″ x 7″	56 lbs.

Note: In continuous runs ¼″ saved when end flutes are removed. Can be suspended on Guth Hangers.

EGGCRATE TRUCOLITE



Light Curve Eggcrate Trucolite

Shielded-Direct Luminaire. Eggcrates hinged on one side and lift off for cleaning. Fixture, Reflector and Eggcrates finished 300° White. Soft up-light for ceiling illumination. Also available with open bottom or glass diffusing bottom. Efficiency: 67.5%, (60.5% down-light, 7% up-light). Maintenance Factor: .70.

GRUBER BROTHERS INC.

72–78 Spring Street
New York 12, N. Y.

DESIGNERS MANUFACTURERS

Since 1922

Gruber Fresnelites are designed (1) to shield the lamps; (2) to reduce glare; (3) to provide a wide diffused candle power distribution; (4) completely enclosed for low maintenance; (5) so that profile of lens helps to spread light across the ceiling to provide a luminous background for the units.

By means of combining incandescent with fluorescent, the warmth of the incandescent can be mixed to relieve the flatness and coldness of fluorescent lighting. The adjustable mechanical features permit the arranging of display first, and then applying the lighting for the best effect.

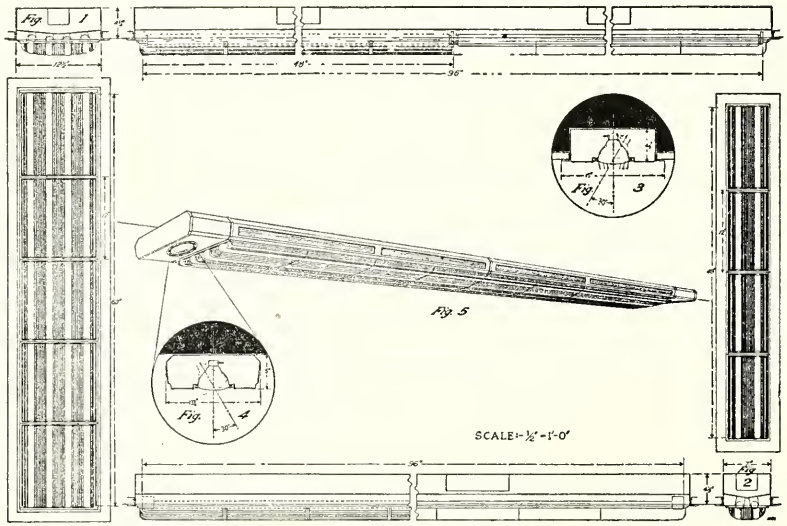


Fig. (1)—No. RF-746—4 lt. Recessed

Fig. (2)—No. RF-750—2 lt. Recessed

Fig. (3)—No 920-GL—1 S. P. par lamp—with Gimbal Ring and Louver—Recessed

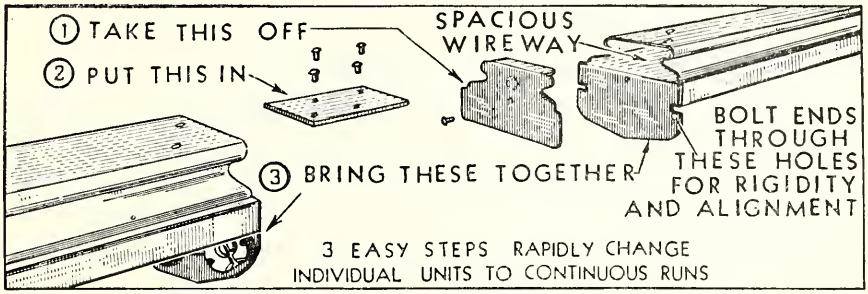
Fig. (4)—No. 914- —1 S. P. par lamp—with Gimba Ring-Surface

Fig. (5)—No. F-812—4 lt—or No. F-822—2 lt—surface

Construction permits the use o single fixtures or joined together to produce continuous lengths of patterned lighting in any combination of incandescent, fluorescent, slimline, or cold cathode for recess or surface mounting.

HOLDENline CO.

2301 Scranton Road
Cleveland 13, Ohio



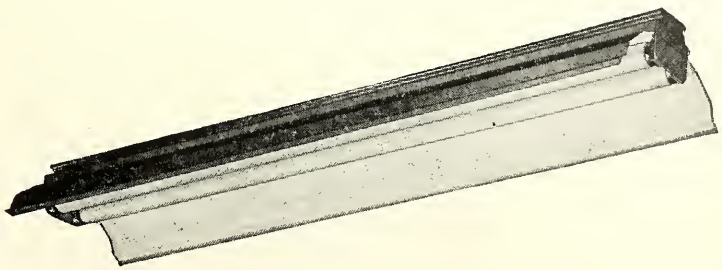
Conversion to Continuous Run is just that easy.

1. HOLDENline Chan'l-Run with its rigid steel channel, its photometrically designed reflector and its engineered accessories was created for ease of installation. Photometric output is designed for an overall efficiency of not less than 79% of the output of the lamps. Shielding angle designed to 14 degrees.

2. HOLDENline BASIC UNIT SYSTEM permits quick and easy conversion to continuous run—using standard units whenever stepped up lighting is desired.

3. With HOLDENline CHAN'L-RUN you get no warping or twisting—butt-on sockets securely mounted on heavy welded steel end plates prevent falling lamps and socket breakage.

4. HOLDENline BASIC UNIT SYSTEM is the product of careful engineering—with spacious freeway for wiring—positive positioning of lamps within the reflector equalizing brightnesses, thus eliminating dark areas between lamps in the fixture—complete flexibility and interchangeability in fluorescent lighting.



HOLOPHANE COMPANY, INC.

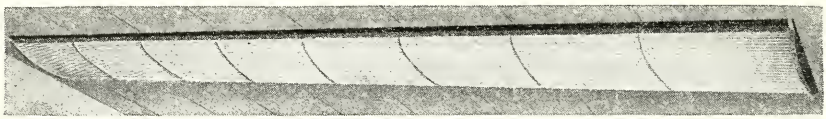
342 Madison Avenue, New York 17, New York

Holophane Engineering Service is offered in two forms: (1) through district engineers locally; (2) through the Application Engineering Department at headquarters. In either case, it is free and without obligation. This counsel is usually offered through the Architect or Engineer to his client and supplements his advice.

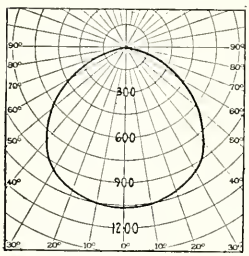
HOLOFLUX FLUORESCENT LIGHTING

OPTICAL FEATURES—The control member of Holoflux lighting systems is the 9100 prismatic Controlens which gathers light from the lamp and redirects it into an intensive downward pattern. Glare is thus minimized at normal viewing angles. Consisting of clear crystal glass, the Controlens will not warp or deteriorate and may be restored to initial condition by the application of soap and water.

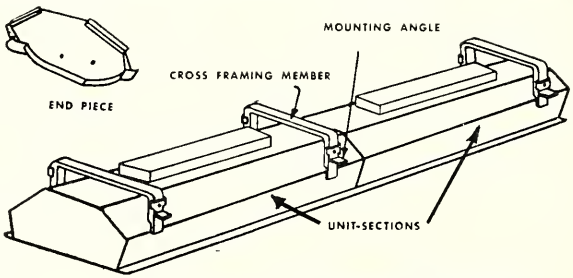
MECHANICAL FEATURES—Basic unit-sections are 4′ in length. They may be used singly or ganged together. Construction is rugged, yet simple, and permits mounting in any type of ceiling —being adjustable to compensate for uneven surfaces.



Extended run (8′) consisting of two Holoflux unit-sections.



Candlepower distribution (4′ fluorescent unit-section) 2–40 W. "F" lamps—4200 lumens.



RECESSING DEPTH–ALL FLUORESCENT UNIT-SECTIONS–6⅜″

All Holophane fluorescent unit-sections are wired.

Basic unit sections take a choice of lamp, ballast, and switching accommodations.

HOW TO SPECIFY RECESSED HOLOFLUX

Units or runs comprise four basic elements: (1) unit-sections; (2) end pieces; (3) cross-framing members; (4) mounting brackets. Where layout calls for individual 4′ fixtures specify: (1) one unit-section per fixture; (2) two end pieces per fixture; (3) two cross-framing members per fixture; (4) two pairs of brackets per fixture.

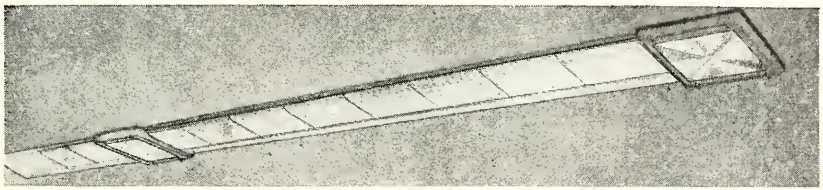
Where layout calls for runs specify: (1) number of unit-sections by dividing length of run in feet by four; (2) number of end pieces, two to each run; (3) cross-framing members, two to the first unit-section of any run and one to each additional unit-section completing the run; (4) mounting brackets, one pair per cross-framing member. *Note:* Special-purpose 2′ and 8′ unit-sections available.

All photometric data is secured from the Holophane Photometric Laboratories in Newark, Ohio.

HOLOPHANE COMPANY, INC.

342 Madison Avenue, New York 17, New York

HOLOFLUX IN COMBINATION WITH INCANDESCENT INSERTS

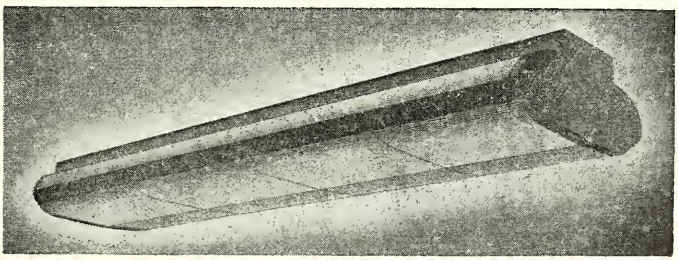


Photograph showing incandescent inserts used with a run of Holoflux Number 9100 fluorescent unit-sections.

Incandescent Controlens units may be added to the Recessed 9100 series to obtain color balances and/or display effects. There are two types of incandescent inserts: (1) intensive units, interspersed on regular spacings with general fluorescent lighting; (2) "Modelite" type with adjustable mechanism for spotlighting effects.

Inserts may be located either between unit-sections (intermediate) or at extremities (ends).

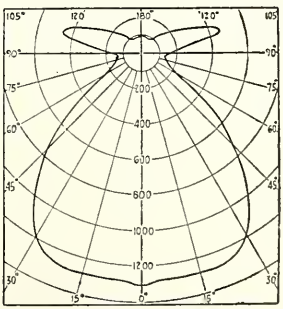
SURFACE-ATTACHED HOLOFLUX—9110 SERIES



Surface-Attached Holoflux Number 9110–9111–9112.

Controlens is the same (9100) as used in recessed type. An upper prismatic member is added to act as: (1) reflector to send more light to the lens; (2) refractor to spread light across ceiling. Distribution is intensive with 70% of total output in 0 to 60° zone and 19% upward towards ceiling. Spacing ratio for uniform illumination is $1\frac{1}{4}$ times the mounting height.

Units may be used singly or ganged together. Unit depth is $8\frac{3}{8}$". Hangers are available for suspension mounting. Lamp holders are wired to the ballast and length of wire provided to reach from ballast to outlet box.

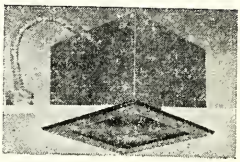


Candlepower distribution Number 9111 across axis of lamps. 3-40 w. F lamps—6300 lumens.

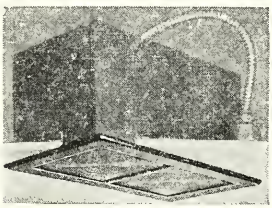
HOLOPHANE COMPANY, INC.

342 Madison Avenue, New York 17, New York

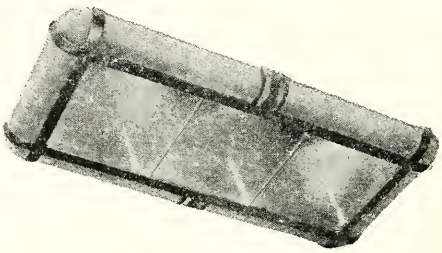
IN-BILT INCANDESCENT LIGHTING—Built-in lighting is in demand for the lighting of many types of commercial and institutional interiors. To meet the varying conditions of space and purpose, Holophane offers three types of Controlens In-bilt units, classified by distribution: (a) symmetrical intensive; (b) symmetrical with variable focus and offset beam; (c) asymmetric—beam widths greater in one direction than in another.



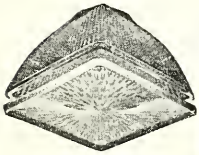
Single unit flush



Multiple unit flush



Multiple unit drop-trim



At right: Diagram showing light control action

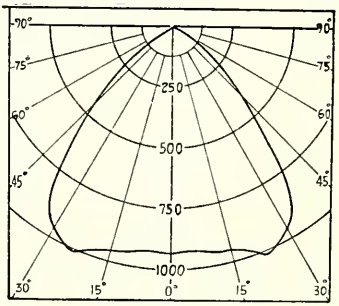
At left: Square Controlens and reflector combination



BASIC OPTICS of the symmetrical intensive units consist of a square Controlens and a square reflector. Brightness is distributed uniformly over the lens surface and glare at normal viewing angles is reduced to a minimum. Number 1774 series uses 12″ Controlens with 300 w. lamp maximum per lens. Number 1748 series uses 8½″ Controlens with 150 w. lamp maximum per lens.

SPECIAL-PURPOSE CONTROLENS UNITS

Other control forms, having concentrating and/or asymmetric distributions for specialized purposes, are available. A few of these are: 1. high ceiling conditions; 2. blackboards, control boards and vertical surfaces; 3. store display and counter lighting; 4. special applications —surgical, artistic, ecclesiastical.



Candlepower distribution
No. F-1774—200 w. lamp
3640 lumens

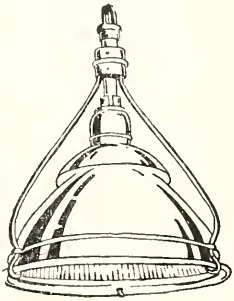
STANDARD CONSTRUCTIONS—Designs are available in either flush or drop-trim type and in single or multiple lens combinations. In single units, face plate is hinged to act as the door. In multiple units, lenses may be slid one on top of the other for easy access. All units carry Underwriters' approval.

HOLOPHANE COMPANY, INC.

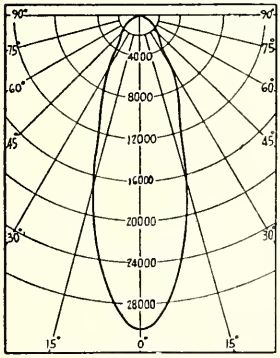
342 Madison Avenue, New York 17, New York

TYPICAL HOLOPHANE INDUSTRIAL LIGHTING UNITS

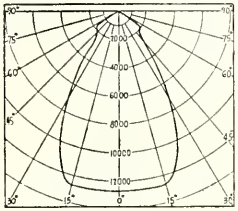
HIBAY REFLECTORS—Heavy duty units for high mounting above craneways in heavy industry, turbine rooms, etc. Also used extensively in hangars and sport arenas. Available in concentrating, intensive and extensive distributions to meet all spatial patterns, and interference conditions. Construction is rugged for safe, trouble-free operation. An aluminum cover is spun on and sealed over the prismatic reflector for added strength and ease of maintenance.



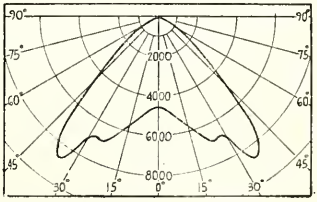
Below: Distribution patterns.



Above: Concentrating type.

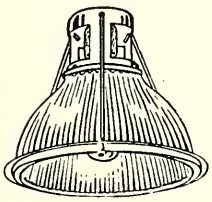


Intensive type.

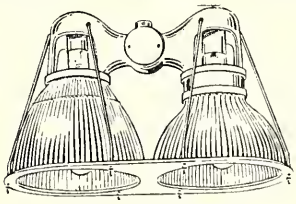


At right: Extensive type.

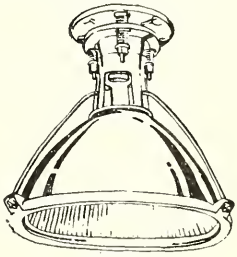
OTHER HOLOPHANE INDUSTRIAL UNITS



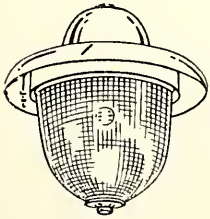
Lobay.



Combination unit.



Cranelite.



Widespred.



Vapor or dust tight.

A broad selection of units (incandescent and fluorescent) is available to meet the varied lighting needs of industry and commerce. A few of these are illustrated above. In addition to these, there are special units for substations, test cells, paint spray booths, blast furnaces, underpasses, warehouses, utility areas, etc.

THE JONES METAL PRODUCTS CO.

West Lafayette, Ohio

DISTRICT REPRESENTATIVES

H. W. MacLeod Co., Boston, Mass.
W. J. Wickenheiser, New York, N. Y.
H. G. Anschuetz, Philadelphia, Pa.
R. G. Montgomery, Baltimore, Md.
R. H. Witherspoon, Atlanta, Ga.
D. K. Post & Co., Syracuse, N. Y.
Wm. E. Hawley, Pittsburgh, Pa.
Wagner-Green Co., Cleveland, Ohio
K. T. Beck, Detroit, Mich.
D. E. Keppler, Indianapolis, Ind.
McKinley Mockenhaupt Co., Chicago, Ill.
C. H. Jerdee Sales Co., Minneapolis, Minn.
Hawkins Electric Sales Co., St. Louis & Kansas City, Mo.
Fred H. Simmer Co., Dallas, Tex.
Fred E. Staible & Sons, Denver, Col.
O. W. Coombs, Los Angeles & San Francisco, Calif.

ABolite

Porcelain Enameled Steel Incandescent Lighting

Reflectors and Floodlights

Industrial Lighting Reflectors—RLM Standard Dome, Shallow Dome, Deep Bowl, Symmetrical and Elliptical Angle, in standard sizes 60–1500 watts. Formed Neck (Socket type), Threaded Neck (R.R. type), Heel Neck (Shade Holder type), Easy Detachable, Separable Socket and Duo-Move Maintenance System.

Glass-Steel Diffusers—Formed Neck, Threaded Neck, Separable Socket and Duo-Move—200–1000 watt.

Mercury Vapor Lamp Units—Low and high mounting types.

High Mounting Incandescent Lighting Units.

Utility Lights (Yardlights)—Gooseneck and Straight Bracket types.

Sign Reflectors—Easy Detachable, Angle. Symmetrical, Elliptical, Rectangular and Emblem sign types.

Adjustable Floodlights (Rayolites) 100–1500 watt.

Open Type Floodlights, 500–1500 watt, with open and concealed wiring brackets for cross-arm, pole, pipe, or wall mounting.

Island Lights—Service Station Units.

Aligners, reflector holders, outlet box covers, dust covers, wire guards and other accessories.

Catalog with specifications, dimensions, weights and other descriptive data furnished on request.

Member of:—

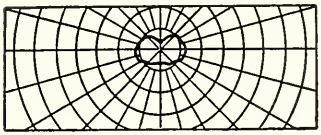
RLM Standards Institute
National Electrical Manufacturers Association.

JOSLYN MFG. & SUPPLY CO.

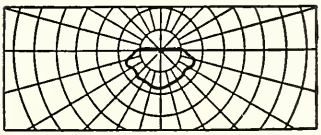
Chicago, Ill.

Manufacturers of Street Lighting Equipment

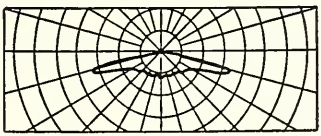
This comparative candle power distribution data was compiled in our laboratory. A 6.6 ampere; 6000 lumen; PS40 clear bulb; C2 filament; mogul base; street series service lamp was used and the tests made at a distance of ten feet. The full lines indicate the vertical candle power and the dotted lines the lateral candle power in the cone of maximum intensity.

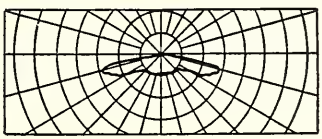
Vertical candle power distribution of 6.6 ampere, 6000 lumen series lamp only.

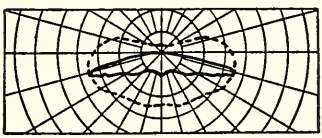
Vertical candle power distribution of open type, exposed light source, luminaire equipped with enameled radial bowl reflector.

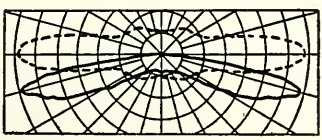
Vertical candle power distribution of open type, concealed light source, suburban luminaire equipped with high strength, aluminum coated, glass reflector.

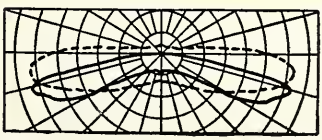
Vertical candle power distribution of enclosed type luminaire equipped with alzak aluminum reflector and clear rippled globe

Vertical and lateral candle power distribution of enclosed luminaire equipped with alzak aluminum reflector, clear rippled globe and inner deflector.

Vertical and lateral candle power distribution of enclosed luminaire equipped with alzak aluminum reflector and Holophane refractor (2 way distribution).

Vertical and lateral candle power distribution of enclosed luminaire equipped with alzak aluminum reflector, Holophane refractor (C-way distribution) and house shield.

Illumination Data from tests by Company Laboratory

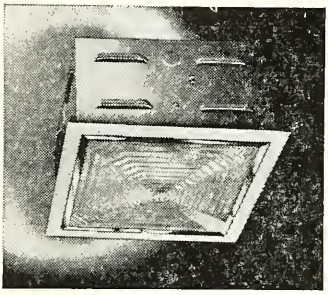
THE KIRLIN COMPANY

3435 E. Jefferson Ave., Detroit 7, Mich.

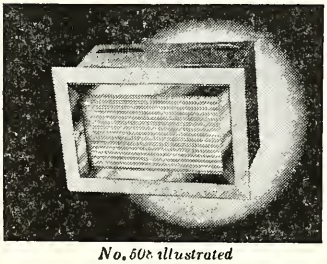
REPRESENTATIVES AT

Boston, Mass.
Chattanooga, Tenn.
Chicago, Ill.
Columbus, O.
Dallas, Texas.
Denver, Col.
Detroit, Mich.
Des Moines, Ia.
Greensboro, N. C.
Indianapolis, Ind.
Washington, D. C.

Los Angeles, Calif.
Milwaukee, Wisc.
New Orleans, La.
Philadelphia, Pa.
Pittsburgh, Pa,
Richmond, Va.
Riviera, Fla.
St. Louis, Mo.
St. Paul, Minn.
San Francisco, Calif.
Seattle, Wash.
Syracuse, N. Y.



No 1208 illustrated



No. 608 illustrated



INCANDESCENT RECESSED

With alzak GlasSurfaced aluminum reflectors

For *Wide* Distribution of Light (square)

Cat. No.	*Max. Watts.*	*Size for ceiling opening.*
1207	100	$7\frac{3}{4}$ x $7\frac{3}{4}$ x $5\frac{1}{8}$ deep
1208	150	$9\frac{1}{4}$ x $9\frac{1}{4}$ x $5\frac{1}{2}$ deep
1212	300	med. $13\frac{1}{4}$ x $13\frac{1}{4}$ x $7\frac{5}{8}$ deep
1512	300	(ditto, clear lens center)
1218	500	mog. $19\frac{3}{8}$ x $19\frac{3}{8}$ x 13 deep

For Concentrating Distribution of Light

1409	150	$9\frac{1}{4}$ x $9\frac{1}{4}$ x $5\frac{1}{8}$ deep
1412	300	$13\frac{1}{4}$ x $13\frac{1}{4}$ x $7\frac{5}{8}$ deep

All may be had with top of box removable for relamping from above ceiling (extra).

RECTANGULAR INCANDESCENT

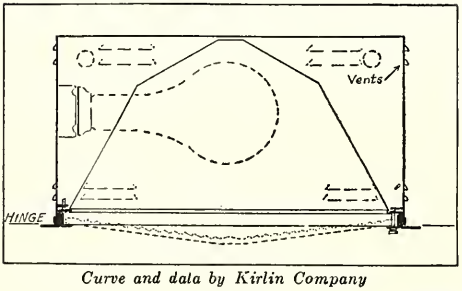
414	40w-TS lamp,	$14\frac{1}{8}$ x $3\frac{3}{4}$ x 4 deep
508	100	$8\frac{1}{2}$ x $5\frac{1}{2}$ x 6 deep

Alba-lite glass; finish, satin stainless door, white ground coat frame.

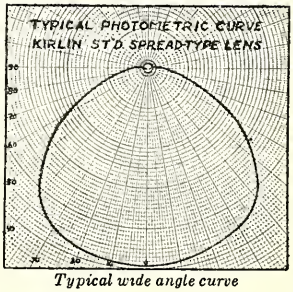
EXITS, RECESSED FLUSH

4506 6″ letters $8\frac{5}{8}$ x $13\frac{1}{8}$ x $3\frac{5}{8}$ deep
4516 "No-Guard" 6″ letters, size above. "No-Guard" type hinged exit requires no guard in gym, is sufficiently strong. Supplied with 2 sockets at extra charge.

All units have Underwriters Lab. labels, union labels.



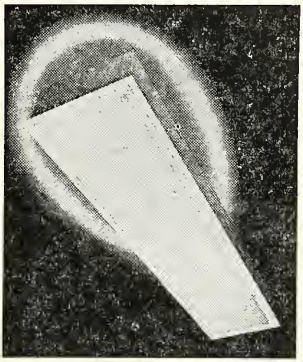
Curve and data by Kirlin Company



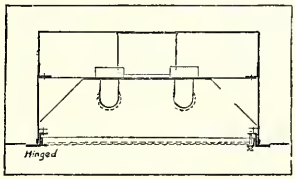
Typical wide angle curve

THE KIRLIN COMPANY

3435 E. Jefferson Ave., **Detroit 7, Mich.**



No. 240B illustrated



RECESSED FLUORESCENT

Designed for wide distribution of light using Alba-lite glass.

Finish, white ground coat for painting.

Reflectors, baked synthetic enamel.

Alzak GlasSurfaced aluminum reflectors also available, special. Lamps spaced $3\frac{1}{2}''$.

HPF ballasts, hinged doors, Und. Lab. label.

Two lamp units fit 12″ acoustic tile ceilings.

Frames are separately adjustable, to pull flush, and made for individual sections or continuous runs.

Available for 3-40w lamps also (special).

Hinged Door Type (Alba-lite glass)	Size for ceiling opening	**Open Troffer Type** (louver extra)
No. 220B	2–20w $11\frac{3}{4}''$ x $24\frac{1}{2}''$ x $6\frac{1}{4}''$ deep	No. 220TR
No. 420B	4–20w $16\frac{3}{8}''$ x $24\frac{1}{2}''$ x $6\frac{1}{4}''$ deep	No. 420TR
No. 230B	2–30w $11\frac{3}{4}''$ x $36\frac{1}{2}''$ x $6\frac{1}{4}''$ deep	No. 230TR
No. 240B	2–40w $11\frac{3}{4}''$ x $48\frac{1}{2}''$ x $6\frac{1}{4}''$ deep	No. 240TR
No. 440B	4–44w $16\frac{3}{8}''$ x $48\frac{1}{2}''$ x $6\frac{1}{4}''$ deep	No. 440TR

KIRLIN DISC-LOUVER

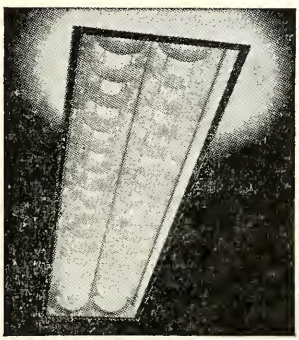
White baked enamel on steel.

48″ louver weighs 11 oz.

Full size $4\frac{1}{4}''$ wide, discs may be interlocked on 2 lamps. Snaps on the lamp.

No. 100D	length 60″	100w.
No. 48D	length 48″	40w.
No. 36D	length 36″	30w.
No. 24D	length 24″	20w.
No. 18D	length 18″	15w.

Only in std. cartons, 24 one size.



No. 240TR with 48D

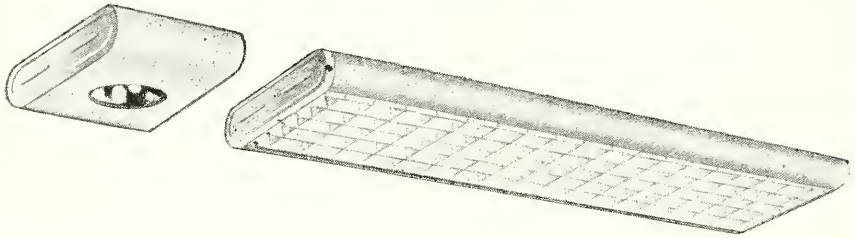


No. 48D snap-on louver, Pat. 2299276

LEADER ELECTRIC MFG. CORP.

6127 North Broadway, **Chicago 40, Illinois**

West Coast Factory: 2040 Livingston Street, Oakland 6, California.



VL—440 Cut—45°

Model VL-440 is arranged for use with four 40-watt, 48 inch, T-12 fluorescent lamps. It can be mounted singly or in continuous runs, suspended at any convenient height, or attached direct in the ceiling surface. Moulded translucent side panels or high gloss white enamel steel panels; specify on order. Available in 45° and 31° louvers. Fixtures in continuous rows can be serviced from the inside without removing a complete unit.

Wired units include sockets, type FS replaceable starters and two U.L. and E.T.L. approved high p.f. 2-lamp ballasts. Conventional 110–125 volts, 60 cy., ac. Other voltages and frequencies on request. Also available for instant start operation. Ceiling tracks supplied for ceiling mounting. Hangers, stems, ceiling strap and canopy furnished for pendant mounting. Connecting bands furnished for continuous run installations at no extra charge.

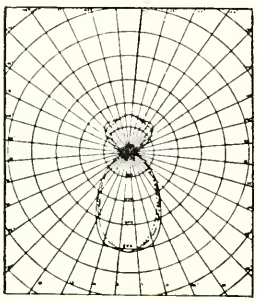
Dimensions: Individual Unit—Length $49\frac{11}{32}$″, Width $16\frac{1}{16}$″
Height $5\frac{3}{16}$″.
Continuous rows—Length $49\frac{7}{32}$″, Width $16\frac{1}{16}$″
Height $5\frac{3}{16}$″.

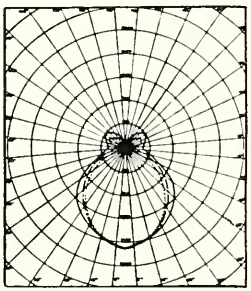
Packed in individual cartons. Shipping weight 50 lbs. Stems and canopy. Shipping weight 5 lbs.

Candlepower Distribution Curves

Commonwealth Edison Laboratory—Longitudinal and Transverse cut-off.

45° CUT-OFF





31° CUT-OFF

DIRECLITE

LS-70

Available for 4 light fixtures. Mount the Leader Adjustable Spotlight over display merchandise and you get an inconspicuous yet effective lighting source.

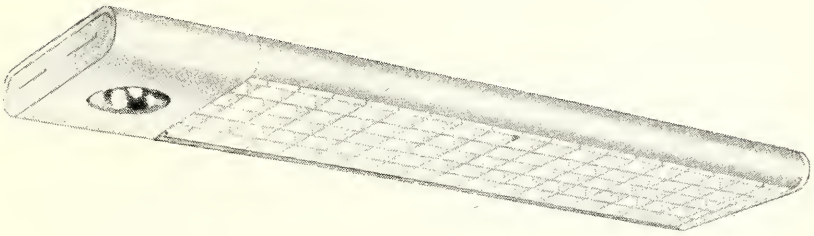
Easily installed to any "Officer" unit whether at the end of a single unit or between units in a continuous run.

VL-440 Installations

Cat. No. LS-70 takes P.A.R. 38 Bulb. Both ends open for VL-440 continuous run.
Cat. No. LS-71 takes P.A.R. 38 Bulb. Open one end for VL-440 single unit.
Dimensions: Length $10\frac{1}{8}$″ (side) Width $16\frac{1}{16}$″ (end) Height $5\frac{1}{2}$″.
Packed in individual cartons. Shipping weight 10 lbs.

LEADER ELECTRIC MFG. CORP.

6127 North Broadway, Chicago 40, Illinois
West Coast Factory: 2040 Livingston Street, Oakland 6, California.



VL—240 Cut—45°

Model VL-240 takes two 40-watt, 48-inch, T-12 fluorescent lamps. Extreme slenderness in width as well as in height give this luminaire the graceful streamlined contours desired for modern architectural effects. Moulded translucent side panels or high gloss white enamel steel panels. Available in 45° and 31° louvers. Fixtures in continuous rows can be serviced from the inside without removing a complete unit.

Wired units include sockets, type FS replaceable starters, and U.L. and E.T.L. approved high p.f. 2-lamp ballasts.

Conventional 110–125 volts, 60 cycle, ac. Other voltages and frequencies on application. Also available for instant start operation.

Ceiling tracks supplied for ceiling mounting. Hangers, stems, ceiling strap and canopy furnished for pendant mounting. Connecting bands furnished for continuous run installations.

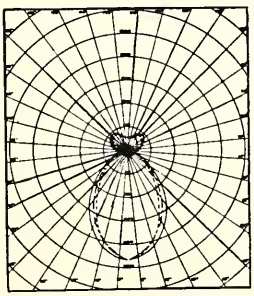
Dimensions: Individual unit —Length $49\frac{11}{32}''$, Width $10\frac{3}{16}''$
Height $5\frac{3}{16}''$
Continuous rows—Length $49\frac{7}{32}''$, Width $10\frac{3}{16}''$,
Height $5\frac{3}{16}''$.

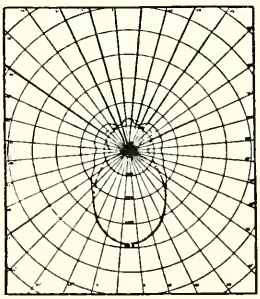
Packed in individual cartons. Shipping weight 30 lbs. Stems and canopy. Shipping weight 5 lbs. Available in 45° and 31° louvers.

Candlepower Distribution Curves

Commonwealth Edison Laboratory—Longitudinal & Transverse Cut-off.

45° CUT-OFF





31° CUT-OFF

DIRECLITE

LS-60

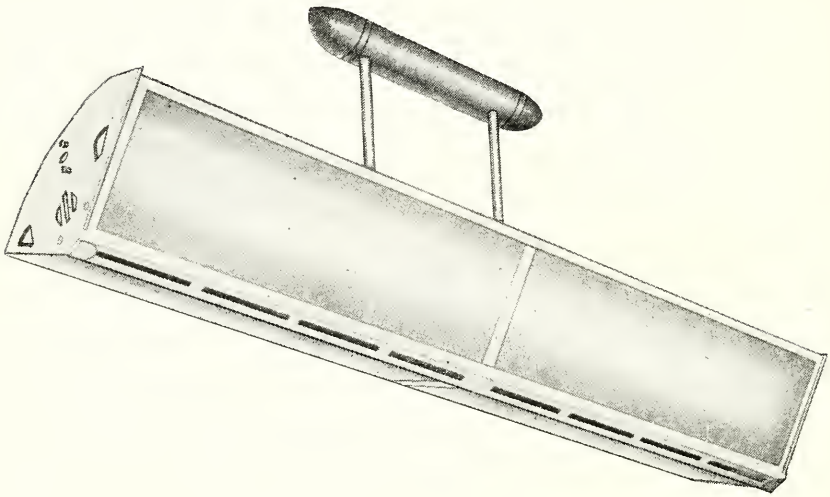
VL-240 Installations

Cat. No. LS60 takes P.A.R. 38 Bulb. Both ends open for VL-240 continuous run.
Cat. No. LS61 takes P.A.R. 38 Bulb. One end open for VL-240 single unit.
Dimensions: Length $10\frac{1}{8}''$ (side) Width $10\frac{3}{16}''$ (end) Height $6\frac{1}{2}''$.
Packed in individual cartons. Shipping weight 9 lbs.

LEADER ELECTRIC MFG. CORP.

6127 North Broadway, **Chicago 40, Illinois**

West Coast Factory: 2040 Livingston Street, Oakland 6, California.



GL-440

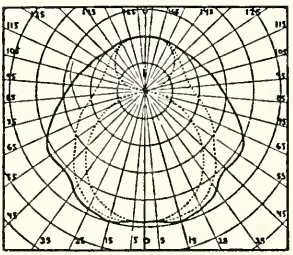
Specifications

Model No. GL-440—Designed for four T-12 40-watt lamps. Tulamp high power factor ballast and replaceable FS4 starters. Over-all length $48\frac{3}{16}''$. Over-all width $13\frac{3}{8}''$. Height $7\frac{3}{4}''$. Frame 18 gauge, housing 20 gauge cold rolled prime quality steel. Finished in satin aluminum, reflector finished in white high gloss, chip proof baked enamel. Skytex Ribbed Glass Panels are used for low surface brightness at normal viewing angles. Stem and canopy assembly No. C-450 available for pendant mounting.

110 volts—60 cycle, ac operation wired complete, ready to install. Other voltages on request. Also available for instant start operation. Shipping weight 48 pounds.

Candlepower Distribution Curve

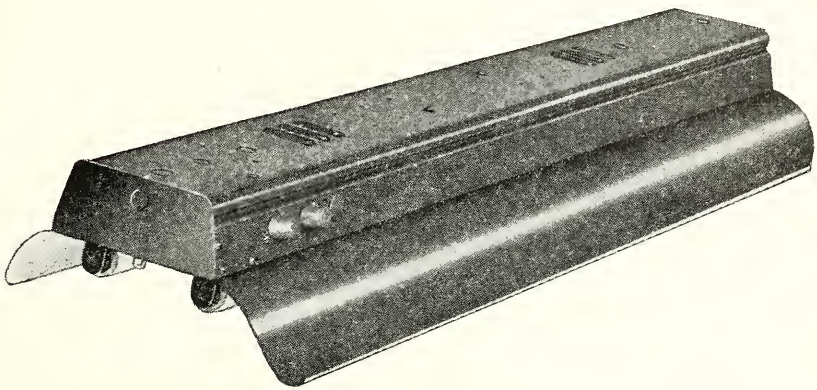
(Commonwealth Edison Laboratories)



M-92

LEADER ELECTRIC MFG. CORP.

6127 North Broadway, Chicago 40, Illinois
West Coast Factory: 2040 Livingston Street, Oakland 6, California.



STRATOLINER SERIES

IUO-240

Open End Reflector (Finished Baked Enamel or Porcelain Enamel).

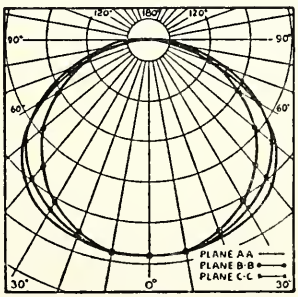
All-steel heavy duty lighting unit for two, 40-watt, T-12 fluorescent lamps. Encloses all auxiliary equipment in accessible channel. This unit can be installed individually or in continuous rows. For direct-to-ceiling or suspension mounting by means of various accessories. Knock outs in channel are placed at convenient intervals. Choice of Baked Enamel or Porcelain Enamel Reflectors. All reflectors are equipped with captive knurled nut for easy servicing. Closed end reflectors available in porcelain only.

Completely wired and reday to install, including Underwriters' Laboratories and E.T.L. approved 95% p.f. corrected ballasts, twist lock sockets, and replaceable starters. Available also for instant start operation. Conventional 110–125 volts, 60 cy., ac. Other voltages and frequencies on request.

Housing and exterior finished gray baked synthetic enamel, highly efficient, white reflector surface. Auxiliary mounting holes provided for future conversion to 3-lamp unit. Shipping weight 31 lbs.

Also available for 2-100 watt lamps; both open and closed end reflectors.

Candlepower Distribution Curve
(Electrical Testing Laboratories)



M-93

PLASKON DIVISION, Libbey-Owens-Ford Glass Company

2125 Sylvan Avenue • Toledo 1, Ohio.

OFFICES:

CHICAGO, NEW YORK, ROCHESTER • C. D. LAMOREE IN LOS ANGELES, SAN FRANCISCO AND SEATTLE: IN CANADA: CANADIAN INDUSTRIES, LTD., MONTREAL, P. Q.

Manufacturers of Molding Compounds for Lighting Reflectors and Equipment.

PLASKON
TRADE MARK REGISTERED
MOLDED COLOR

The unique properties of Plaskon Molded Color in illumination account for its widespread acceptance and use in this field. These properties include the high overall lighting efficiency of the material, its light weight, its strength, its shatter-resistant qualities, and its ability to take unusual forms and shapes economically.

Plaskon plastic materials for illuminating purposes are produced in a variety of types, ranging from translucent whites and colors of excellent, uniform light transmission and agreeable diffusion, to opaque whites with high reflection factors. Throughout this range of types and colors lighting efficiencies remain good, since Plaskon plastics absorb only a small amount of the total bare bulb output.

With the hundreds of pastel colors available, Plaskon plastics are widely used in the field of decorative and domestic lighting. They lend themselves ideally to the modern trend toward louvered, cove and fenestrated illumination.

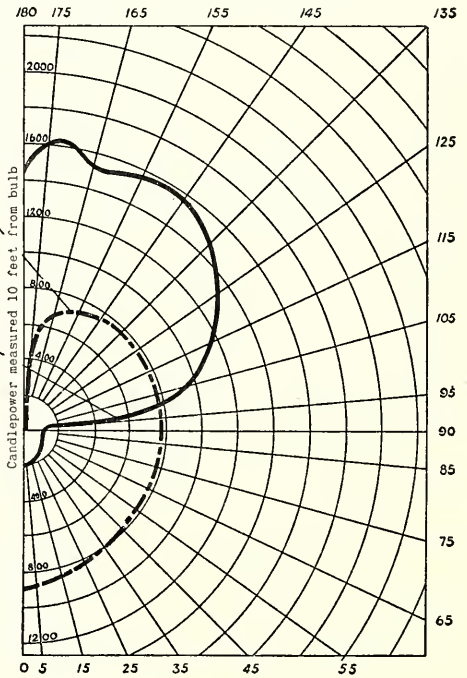
Candlepower Distribution Curve of Plaskon Molded Color Reflector

15" Open Bowl Reflector
Semi-Opaque Urea Plastic
500-watt Gas Filled Bulb

Light Distribution Bare Bulb

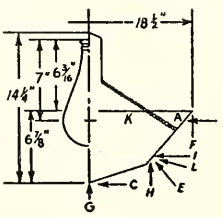
Light Redistribution Using Plastic Reflector

Light Source



Light Output Data

Zone	Percent Light Output Bare Bulb
0–60°	5
0–90°	8
90–180°	75
Efficiency	83



Brightness

Location	A	B	C	D	E	F
Candlepower per sq in.	0.5	0.5	1.1		1.4	0.3
Location	G	H	I	J	K	L
Candlepower per sq. in.	1.2	1.1	1.3		0.5	1.3

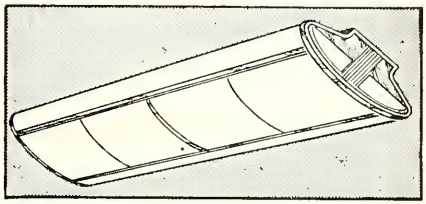
Illumination Data from Electrical Testing Laboratories, Inc.

LIGHT CONTROL COMPANY

3217 Casitas Avenue
Los Angeles 26, California

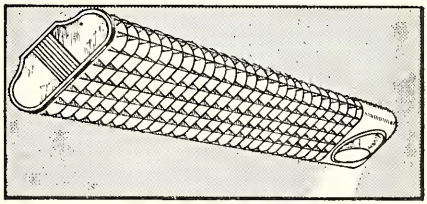
COMMERCIAL

The LCS Series of three and four lamp office fixture. This fixture may be used singly or in continuous runs, surface mounted or stem hung. Sides and top: Lucite diffusing medium. Lower hinged panel: Four prismatic lenses. Length 49″, Width 16″, Height 7″.



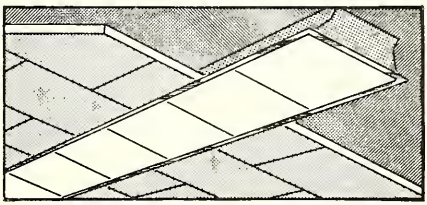
COMMERCIAL

The LCW series of two, three and four light fixtures is effective in single or continuous rows with or without the Flex-a-Lite spot feature, and is provided with all-metal louvre which swings downward for relamping. Length 49″, Width 16″, Height 7″.



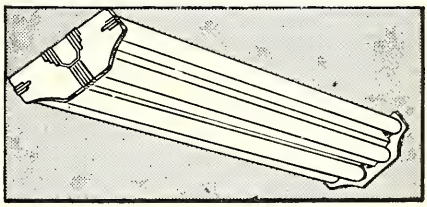
TROFFER

For incandescent or fluorescent lamps, troffer lighting methods permits the use of two, three, four or more lamps, or a combination of incandescent and fluorescent; provides a flexible lighting system of maximum adaptability; custom-made to specification. Also available in six standard types.



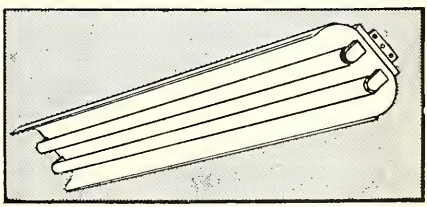
OPEN COMMERCIAL FIXTURE

The LCII series is available in two, three and four lamp types for either ceiling or suspended installation. These fixtures are suitable for installation in large commercial interiors. Length 48″, Width 11″, Height 5″.



INDUSTRIAL

Two and three lamp type. This unit has an all-steel construction with white porcelain enamel reflector and grey baked enamel exterior. Length 48″, Width 12⅝″, Height 7″. (For single unit installation or continuous runs.)



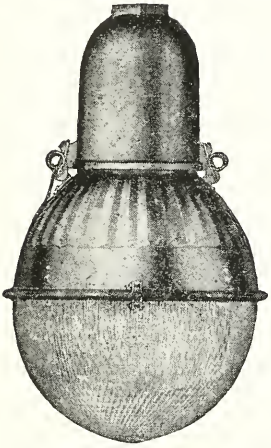
The above illustrations are typical examples of a complete Light Control lighting equipment manufacturing service. At the request of users of the I.E.S. Lighting Handbook, we will be pleased to supply a 60-page General Catalog, containing essential data on lighting equipment manufactured by us.

Established 1929

LINE MATERIAL COMPANY

Executive Office • Milwaukee 1, Wisconsin

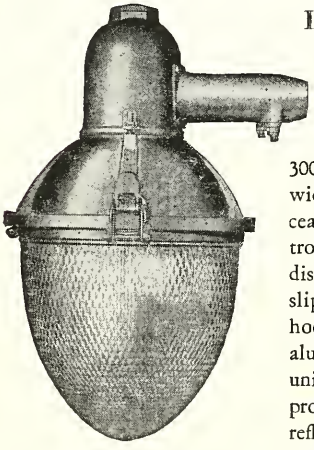
Canada—Canadian Line Materials Ltd.—Toronto 13



Spherolite Luminaire with V-Band Glassware Holder

L-M SPHEROLITE LUMINAIRE

The L-M Spherolite is a suspension luminaire for all modern street lighting installations. This luminaire is especially recommended for use on straight series circuits of 5000 volts or less with lamps up to 10000 lumen series or 500 watt multiple. The luminaire is a concealed light source type. Spherolite hoods are available in a variety of designs to meet all wiring and mounting requirements — for use on brackets, mast arms, or center span. The hood is available as a pendant or side entrance mount, and is furnished for 1¼″ mounting as standard, 2″ mounting if specified. The use of side entrance hoods provide higher mounting height at the same bracket height. Side entrance hoods are available in two distinct styles, one without a heat insulator, the other with a porcelain heat insulator. The Spherolite reflector can also be furnished for direct attachment to porcelain heads. The hood and reflector is made entirely of aluminum. The alzak processed reflector is fluted to prevent destructive heat concentration on the filament stem of the lamp. Various glassware holders are available to meet individual operating requirements. The luminaire is available with light distributions meeting I.E.S. classification for Types I, III, IV, and V and, in addition, a Four Way light pattern for intersection lighting.



Controlite Sr. Luminaire —Side Entrance Hood

L-M CONTROLITE SR. LUMINAIRE

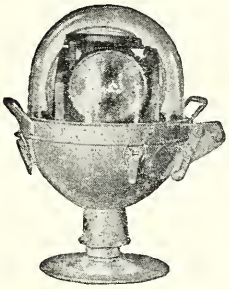
The Controlite Sr is an ornamental suspension luminaire especially recommended for use on straight series circuits of 5000 volts or less with 4000 to 15000 lumen lamps, and on multiple street lighting circuits with 300 to 750 watt lamps. It is ideal for the efficient lighting of wide boulevards and traffic arteries. This luminaire, of the concealed light-source type, offers high efficiency and scientific control of light. It is available for symmetric or assymetric light distribution. The luminaire can be furnished with a side mounted slipfitter hood, with heat insulator, as shown at left, or with a hood for pendant mounting. The hood and housing are cast aluminum protecting an inner reflector of specular alzak. The unit is furnished with a pressure latch glassware holder which provides a constant vertical spring pressure of glassware on the reflector. The diffusing globe furnished with this luminaire is of the self-cleaning diamond mesh design. Light distributions meet I.E.S. specifications for IV and V.

LINE MATERIAL COMPANY

Airport Lighting Division—East Stroudsburg, Pa.

Canada—Canadian Line Materials Ltd.—Toronto 13

ROTATING BEACON FOR SMALL AIRPORTS



A low cost rotating beacon with an optical system consisting of sealed beam lamps mounted on a vertical shaft which is driven by a slow speed synchronous motor. Designed to project two main beams of light, 180 degrees apart, 5 degrees above the horizontal. When the preferred lamps burn out a transfer relay automatically turns on the spare lamps to insure continuity of service. Simultaneously, a tell-tale circuit is energized back to the control center indicating that operation is on the spare lamps. The auxiliary top lamp is tilted slightly off vertical to provide an additional rotating beam which gives excellent high altitude indication. It also provides a simple means for ceiling indication where no ceiling projector is available.

Each unit is furnished with a 3-step transformer which will provide 185,000 cp at rated (115) line voltage for bad weather (500 hour lamp life); 315,000 cp at 120% voltage for emergencies (75 hour lamp life); 110,000 cp at 85% voltage for clear weather (4000 hour lamp life). Total power consumption including lamps and motor is 325 watts.

There are no external rotating parts — all moving parts are enclosed. The slow speed (75 RPM) motor has one single reduction worm gear producing less wear and requiring less lubrication. The sealed beam lamps maintain efficiency throughout life and the enclosed dust-tight construction keeps cleaning and maintenance to a minimum.

Adaptable to mounting on pole or on top of hangar. Approximate net weight, 75 lbs. Approximate overall height, 25¾″.

HIGH INTENSITY RUNWAY AND APPROACH LIGHT

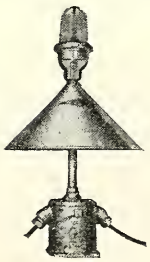


These units provide a powerful beam which is scientifically controlled to give maximum penetration and freedom from glare under all atmospheric conditions. As an example, cockpit visibility is increased to a mile when ground visibility is as low as ⅜ mile.

These lights work with and are supplementary to proper instrument and radio approved procedure. On instruments, a pilot can approach to within his specified minimum altitude and can be within 300 feet of the center line of approach, depending on the skill and confidence of the pilot, wind conditions, and the accuracy of his equipment. The actual landing must be accomplished by visual contact. The pilot must see, not necessarily the runway surface, but its outline by lights which establish a perspective.

The unit consists of an optical system of two lenses and a reflector which controls the light from the lamp. Lamps up to 500 watts providing 180,000 candlepower beam can be used. The outer lens is a large glass dome having vertical prisms on the inner surface which controls the light distribution in a horizontal plane. Portions of the lens are coated with enamel on the inside to limit the transmission of light in undesirable directions. The inner lens is of the Fresnel type which controls the light in the vertical plane.

Approximate net weight 55 lbs; overall height 25¾″; overall width 18¾″.



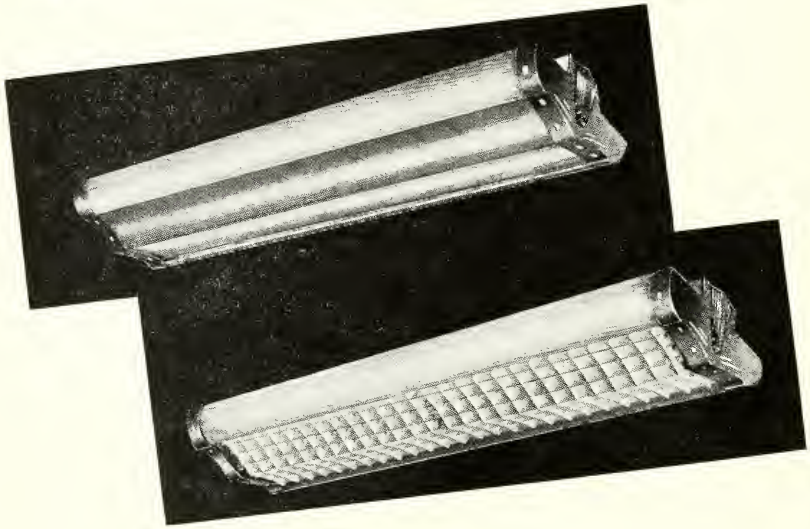
ELEVATED RUNWAY MARKER AND TAXI LIGHT

The controlled beam light distribution of this light provides unobstructed delineation for the pilot. It requires minimum maintenance since it is high enough above the grass line and is particularly suited to snow areas. Series or multiple power supply can be used. A safety feature is provided which breaks the supporting column if struck. Sealed cable entrance prevents moisture from entering the underground cable housing. Optical system is easily removed for relamping and cleaning. The yellow cone aids pilot for daytime identification.

LIGHTING PRODUCTS, INC.

Highland Park, Illinois

Distributed nationally
through leading electrical wholesalers.



The LPI Constellation

The Constellation series 110 is designed to conform to the standards of the Utilities Research Commission. The fixture is a complete unit including top housing, reflector shielding assembly, louvers or glass panels, ballast equipment and lampholders.

All fixtures are wired completely and include starters (removable without disturbing lamps), butt-on lamp holders, and HPF ballasts for 110 volt, 60 cycle, A. C. operation. Ballasts and wireway are completely enclosed in the top housing.

A die-formed reflector is made of 20 gauge steel and is attached to the top housing by two cap nuts. Reflector is easily removable for maintenance and inspection. The reflector is finished with high temperature baked white enamel and provides a reflection factor of 85%.

Side panels are ceramic ribbed glass with a transmission factor not exceeding 30%. Bottom glass assembly consists of two pieces of bent, clear, ribbed glass with brightness and transmission factors as specified by the Utilities Research Commission.

On louvered units, the louvers are of egg-crate design finished in "Klasium White." Louvers are hinged at the ends of the unit and meet at the center where they are held by a spring clamp. The light cut-off of these louvers meets the specifications of the Utilities Research Commission.

Patents pending on all features and designs.

LUMINALL PAINT DIVISION

National Chemical & Manufacturing Co.

Chicago–3617 S. May St. **Brooklyn–25 Forrest St.**

Dealers located in 3,500 leading cities



General LUMINALL paint is widely used as an adjunct to better lighting. This product is a casein and oil emulsion vehicle with lithopone as a pigment. It comes in paste form and thins with water. This method of formulation permits a high ratio of pigment-to-binder, and gives an unusually high light reflection factor in white and the lighter colors.

The lighting qualities of LUMINALL paint are further increased by a patented method of control and grinding which results in the pigment being ground extremely fine. This permits practically complete diffusion of reflected light; thus, there is no specular reflection and glare is minimized.

Uses In addition to LUMINALL paint's high reflection factor and complete diffusion of light, it has a beauty of color and texture that has made it a leader among interior paints and thus it can be made to combine pleasing decorative qualities with maximum light improvement.

Luminall Standard Colors & Light Reflection Values*

White	90.6%
Cream	79.5%
Buff	69.5%
Sea Green	63.5%
Ivory	85.5%
Peach	63.5%
Sunlight Yellow	78.5%
Powder Blue	58.5%
Mist Grey	73.0%
Rose	62.5%
Sage Green	46.0%
Beige	53.0%
Turquoise	67.0%

**Light reflecting values of the above standard colors can be still further increased by adding white.*



A Texas Schoolroom Modernized According to the Harmon Technique

THE HARMON TECHNIQUE IN SCHOOLS

LUMINALL is the paint used in the schoolroom experiments in Mexia and Rosedale, Texas, under the direction of Dr. Darell Boyd Harmon. These experiments which were conducted under the closest possible scientific control and observation revealed that proper painting, fenestration, lighting and seating resulted in giving school children ten months educational gains in six months and many improvements in physical well-being including a marked lessening of eye, dental and nutritional deficiencies. The Harmon Technique is described in the following reprints which will be mailed free on request:

Reprint: Architectural Record, February, 1946, "Light on Growing Children."

Reprint: Nations Schools, May, 1947, "Classroom Lighting—The Harmon Technique."

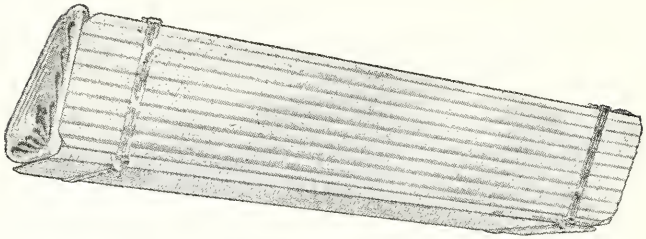
FOR VARIOUS TYPES OF INTERIORS

LUMINALL paint is widely used on factory interiors because its aid to good vision increases production and tends to lower accidents and adds generally to good employee morale. It is especially recommended for large workrooms of all kinds. In this class of work the moderate cost of the paint and the economies of application (one-coat coverage; 40-minute drying; use of wide brush) are important.

LUMINALL is used in all types of commercial and public buildings. In addition to its contribution to lighting, its attractive colors give full latitude to decorative plans.

LITECONTROL CORPORATION

36 Pleasant St., Watertown, Mass.



CORONET FLUORESCENT FIXTURE F-74 S,P, & C.

FIXTURE SPECIFICATION:—

(a) Four lamp "V" shaped glass sided unit.

(b) Side panels of 9″ x 47⅞″ "Pluralite Glare Reducing". * Transmission factor 70%.

(c) Side panels hinged for ease of maintenance, hinging such that panels may be opened from the floor. Panels hinged in such manner that panels may be installed and removed without use of tools.

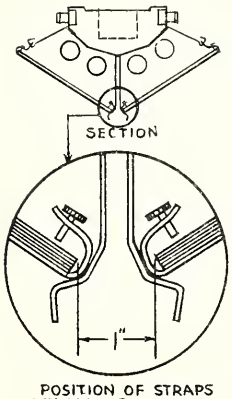
(d) Starters mounted on sides, may be changed without removing lamps.

(e) Body of 20 ga. steel.

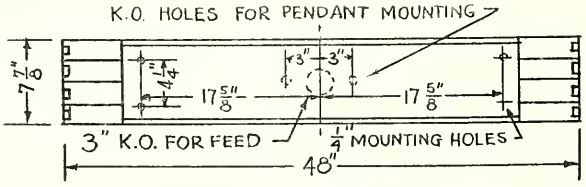
(f) Finished in baked white plastic type finish.

(g) Two double 40 watt high power factor ballasts.

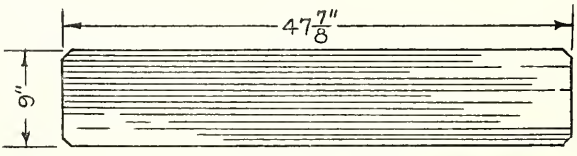
(h) Union wired—Underwriters Laboratory approved.



POSITION OF STRAPS WITH GLASS PANELS CLOSED

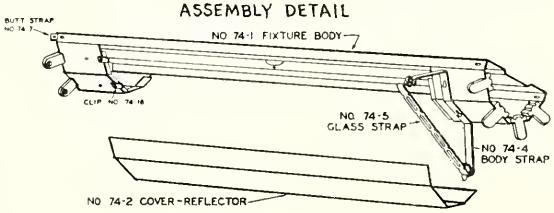


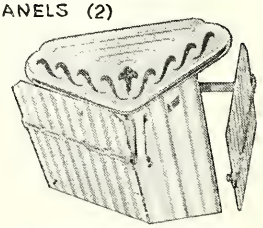
PLAN OF BODY



GLASS PANELS (2)

ASSEMBLY DETAIL





DETAIL SHOWING PANELS OPEN FOR RELAMPING AND CLEANING

* Data supplied by Mississippi Glass Co.

LITECONTROL CORPORATION

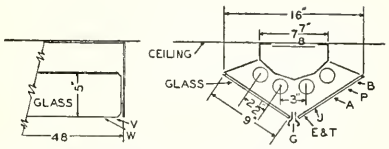
36 Pleasant St., Watertown, Mass.

Report No. 314031 by Electrical Testing Laboratories, Inc. of New York on Candlepower distribution of F-74 Ceiling Type Fluorescent Unit *** as rendered to Litecontrol Corporation, September 14, 1945, in substance is, as follows:

Lamps—Four—40 Watts; 2100 Lumens; 230 Mean Horizontal Candlepower; T-12 3500 degree White Fluorescent.

Unit—White enamel painted reflector, reflection factor 0.79, equipped with two panels of Satinol Luminex glass.

Test—Candlepower distribution in three vertical planes intersecting in the center of the unit; A-A normal, B-B parallel, and C-C 45 degrees to the tubes.



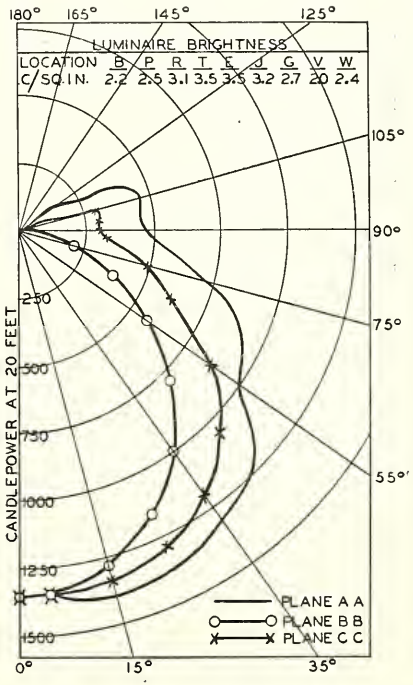
Light output in per cent of bare lamps:

0°–60°—40.5

0°–90°—48.5

0°–180°—68.0

Angles	CANDLEPOWER		
	Plane A-A	Plane B-B	Plane C-C
165°	0	0	0
155°	34.5	10.5	22.5
145°	57	10.5	31.5
135°	75	12.5	46.5
125°	115	13	59
115°	348	15.5	95.5
105°	470	16.5	298
95°	456	17.5	292
90°	474	15	292
85°	530	61	327
75°	720	211	490
65°	910	387	615
55°	985	585	865
45°	1230	795	1060
35°	1320	995	1200
25°	1380	1170	1290
15°	1410	1290	1350
5°	1370	1360	1360
0°	1360	1360	1360



SIZES AND SPECIFICATIONS

Cat. No.	Type	No. of Lamps	Length	Width	Height	Approx. Ship. Wt.	Pendant Length
F74S	Surface	4—40W	48″	16¼″	8¾″	58 lbs.	
F74P	Pendant	4—40W	48″	16¼″	32¾″	63 lbs.	24″
F74C	Cont. surf.	4—40W	48″	16¼″	8¾″	58 lbs.	

*** E. T. L. No. 1045

MARKEL ELECTRIC PRODUCTS, INC.

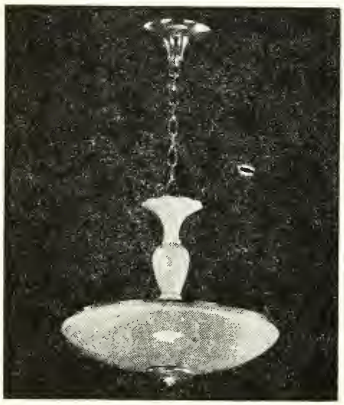
145 Seneca St., **Buffalo, N. Y.**

Manufacturers of lighting equipment for residential and commercial interiors. All fixtures bear the Underwriters' label.

RESIDENTAL LIGHTING FIXTURE # 8285 E.T.L. Report No. 156408

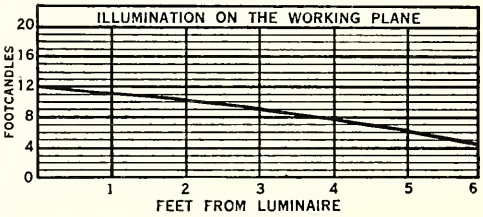
Suspension type $15\frac{3}{8}$" dia. Bowl of beige glass. Five 40 watt A-19 inside frosted bulbs. Maximum brightness of 1.2 candles per square inch occurs in the 0 to 77.5° zone. Maximum ceiling brightness of $\frac{2}{10}$ candles per square inch occurs within a radius of 18 inches.

Illumination values obtained in standard test room as specified in I.E.S. Lighting Performance Recommendations for Residential Luminaires.



LIGHT FLUX VALUES

ZONE	LUMENS		PER CENT TOTAL LUMENS BARE LAMP	PER CENT LIGHT OUTPUT
	5 LAMPS	LUMINAIRE		
0°-60°		240	10	67
0°-90°		359	15.5	
90°-180°		1199	51.5	
0°-180°	2325	1558	67	



RESIDENTIAL LIGHTING FIXTURE # 6855 E T L. report No. 156412

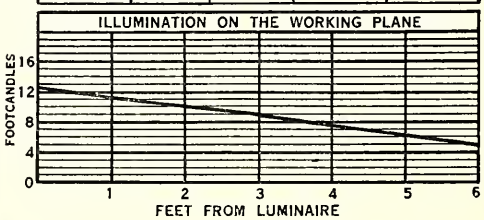
Suspension type. $18\frac{1}{2}$" diameter. Decorated Ivory glass. Uses five 40 watt A-19 bulbs. Maximum brightness of 1.4 candles per sq. inch occurs in the 0-77.5° zone.

Illumination values obtained in standard test room as specified in I. E. S. Lighting Performance Recommendations for Residential Luminaires.



LIGHT FLUX VALUES

ZONE	LUMENS		PER CENT TOTAL LUMENS BARE LAMP	PER CENT LIGHT OUTPUT
	5 LAMPS	LUMINAIRE		
0°-60°		303	13	66
0°-90°		485	21	
90°-180°		1049	45	
0°-180°	2325	1534	66	



Member American Home Lighting Institute

MARKEL ELECTRIC PRODUCTS, INC.

145 Seneca St., Buffalo, N. Y.

Incandescent and Fluorescent luminaires for residential and commercial interiors.

COMMERCIAL LUMINAIRE #5059

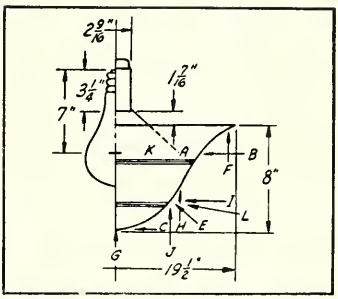
E.T.L. Report No. 144437

Lamp—500 Watts; 115 Volts; 10,000 Lumens; PS40 Inside Frosted Gas-Filled Bulb; C-7A Filament; Mogul Base; General Service. Unit-Composition material. (white)



LUMINAIRE DISTRIBUTION DATA					
MEAN VERTICAL					
MID-ZONE ANGLES	CANDLEPOWER AT 10 FEET	ZONAL LUMENS	MID-ZONE ANGLES	CANDLEPOWER AT 10 FEET	ZONAL LUMENS
180° ZEN.	1490		90° HOR.	121	
175°	1580	150	85°	123	134
165°	1710	484	75°	143	151
155°	1800	831	65°	169	168
145°	1740	1091	55°	192	172
135°	1600	1240	45°	215	166
125°	1420	1275	35°	233	146
115°	1210	1200	25°	255	118
105°	785	788	15°	273	77
95°	149	182	5°	281	27
			0° NADIR	284	

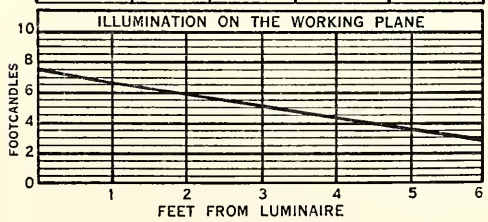
LIGHT FLUX VALUES				
ZONE	LUMENS		PER CENT TOTAL LUMENS BARE LAMP	PER CENT LIGHT OUTPUT
	LAMP	LUMINAIRE		
0°-60°	2666	706	7	84
0°-90°	5200	1159	11.5	
90°-180°	4800	7241	72.5	
0°-180°	10000	8400	84	



RESIDENTIAL LIGHTING FIXTURE #8287

E.T.L. Report No. 156407

LIGHT FLUX VALUES				
ZONE	LUMENS		PER CENT TOTAL LUMENS BARE LAMP	PER CENT LIGHT OUTPUT
	3 LAMPS	LUMINAIRE		
0°-60°		154		66
0°-90°		230	16.5	
90°-180°		689	49.5	
0°-180°	1395	919	66	





Close ceiling type $13\frac{1}{8}$" dia. Ivory Enameled canopy. Ivory glass. Three 40 watt A-19 bulbs. Maximum brightness of 1.1 candles per sq. in. occurs in the 0–77.5° zone. Maximum ceiling brightness of $\frac{1}{2}$ candle per sq. in. occurs within a radius of 18 inches.

Illumination values obtained in standard test rooms as specified in I. E. S. Lighting Performance Recommendations for Residential Luminaires.

All Luminaires Bear the Underwriters' Label.

MAJOR EQUIPMENT CO., INC.

4603-19 Fullerton Ave.

Chicago 39, Illinois

ALZAK PROCESSED ALUMINUM REFLECTORS

ACCEPTED BY LEADING ARCHITECTS, ENGINEERS, AND LIGHTING EQUIPMENT MANUFACTURERS—

Having pioneered in the use of Alzak Aluminum Reflectors for many years and continuously operating under a license agreement with the Aluminum Company of America, whose laboratory developments and experience we have the benefit of, we feel we can be called "Specialists" as we have aspired to, in the proper design of, the complete manufacture of, and the proper processing of, **ALZAK** Aluminum Reflectors of either **SPECULAR,** (Polished) or **DIFFUSED,** (Satin) finish.

Send drawings or samples of your needs for our estimates.

A CAPABLE ENGINEER IN PRINCIPAL CITIES

COAST TO COAST

M-104

JULIAN A. McDERMOTT CORPORATION

40-22 National Street, Corona, L. I., N. Y.

Representatives in Principal Cities

Cold Cathode Lighting, Lighting Products and Protectors

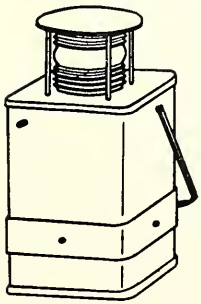
Marine and Aircraft Buoys—Life Saving Signal Lights

Flashing Warning Lights—Traffic Warnings

Electric Lanterns—Inverters

COLD CATHODE LIGHTING. This source offers a full range of colors including reds, blues, whites and pastels. Tubing is available from $\frac{1}{3}$ inch to 1 inch in diameter in either straight lengths or curved sections. From 50 to 450 lumens per foot can be obtained. Operating voltages range from 700 to 15,000 volts depending upon the number and types of tubes used in the secondary circuits. This form of lighting used either alone or as a background for incandescent highlighting would serve for many thousands of hours before replacement would be necessary. With the Underwriters' Laboratories' approval of our Model P-4 Protector, this becomes one of the safest forms of illumination. Both fire and personnel protection is obtained because a ground arc in the high voltage wiring, an open circuit on the secondary, or a grounded person touching a live high tension contact cuts off the power within 3 cycles. If a tube is removed, fails, or is manufactured incorrectly, the P-4 Protector opens the *primary* circuit. No special primary wiring or control is required and operation is fully automatic.

FLASH SIGNAL AND PULSING WARNING LIGHTS. The use of condensers discharging through lamps offers a wide range of light outputs and characteristics for flashing and pulsing signals. Typical of these is the device illustrated. Originally designed during the war for Naval use, it is now being widely adapted for marking street openings, road obstructions, canals, stop signs, and other places where dangerous conditions exist. The lantern illustrated operates for over 1000 hours at 70 flashes per minute and approximately 30 candle power. Other more powerful models are being made which produce thousands of candlepower. One such type placed in front of street workers sends a pulsing beam toward oncoming motorists. Another type used in a marine buoy gives an intensity sufficient to be visible for 10 miles. Flash rates from 12 per minute to 40 per second are obtainable.



Flashing Electric Lantern

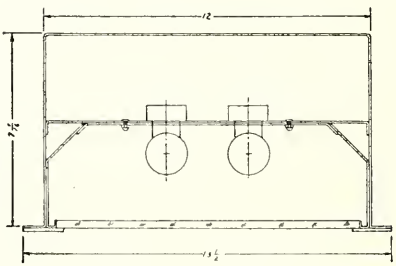
METALCRAFT PRODUCTS COMPANY

306–308 Cherry St., **Philadelphia 6, Penna.**

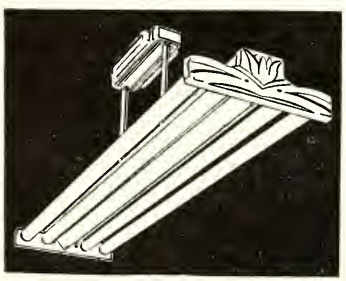
Manufacturers of
*The *MAGNA-LITE LINE of Slimline and*
Fluorescent Fixtures.

SLIMLINE FIXTURES: 1, 2 and 4 lamp channels and Commercial units for the 96T8 lamp are available from stock, wired to provide lamp current of 100 or 200 milliamperes. Ballasts for higher brightnesses will soon be available. *Write for bulletin #SL-100.*

RECESSED UNITS: Standard 2 and 3 lamp units are made only 12″ wide. Wireway is designed to permit ballast heat to radiate from two outside metal surfaces. Stock fixtures are designed for louvres, glass or lens bottoms, and for individual or continuous installations. (Bulletin R447)



FLUORESCENT CHANNELS: 1, 2, 3 and 4 lamp channels in 14w, 15w, 20w, 30w and 40w sizes are stocked by our distributors. Bulletin C946 illustrates construction details that make these units suitable for window-lighting, coves, sign-tracks, showcases, etc. Construction is such that channel length is no greater than nominal lamp length. Symmetric and asymmetric reflectors and other devices are illustrated in bulletin C946.



COMMERCIAL FIXTURES: A variety of bare lamp and shielded units for offices, schools and stores are illustrated in bulletins #3473, #A3474, #X3472 and #CE-3471. All types are made for continuous and individual installation. Unit illustrated at left is also made with hinged bottom louvre and side shielding.

Illustrated bulletins promptly furnished upon request.

**T. M. Reg.*

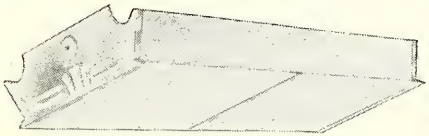
M-106

MITCHELL MANUFACTURING COMPANY

2525 North Clybourn Avenue

Chicago 14, Illinois

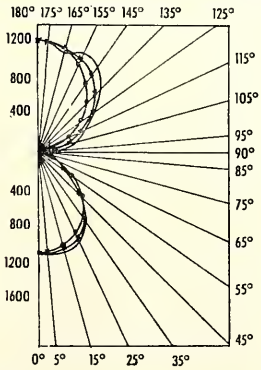
COMMERCIAL FLUORESCENT LUMINAIRES

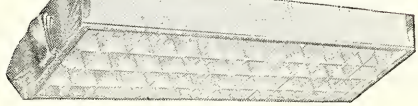


No. 2032. Original U.R.C. Luminaire

Uses 4—40 Watt Lamps

Designed by the Utilities Research Commission. Adaptable for suspension or surface mounting, singly or in rows. Special installation feature: Metal "tracks" furnished are fastened to ceiling with toggle bolts or Ackerman; fixture slides into place on tracks. All-metal channel finished in white Baked Enamel. Satin Aluminum end plates. Side panels are double-strength ribbed ceramic coated glass; bottom panels are double-strength prismatic ribbed glass. For 110–125 volts 60 cycle A.C. operation. For suspension mounting, unit requires Canopy and Stem Set No. 032ST (stems 36″ long, $\frac{3}{8}$″ I.P.). Overall dimensions: $48\frac{3}{4}$″ long, $19\frac{3}{4}$″ wide, 7″ high. E.T.L. curve below. (Stem mounted unit.)

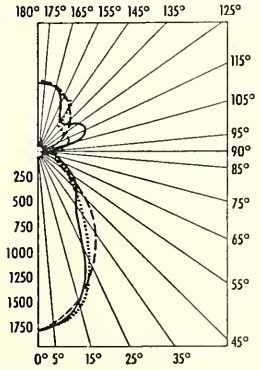




No. 3011 & 3012. DeLuxe Louvered Unit

Uses 4—40 Watt Lamps

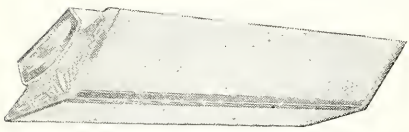
For suspension or surface mounting, singly or in rows. Features full-depth metal louvers at bottom and ceramic treated glass panels on sides. With Satin Aluminum end plates. Model No. 3012 has "Instant-Start" feature; no starters required. Both models have patented "One-man Quick-mount" feature. Louver lifts out easily. All-steel wireway channel and reflector, finished in white Baked Enamel. Certified by E.T.L. and listed by Underwriters' Laboratories, Inc. Power factor over 90%. Stroboscopic corrected. Completely wired, ready to hang. For suspension hanging, unit requires Canopy and Stem Set No. 032ST. For 110–125 volts 60 cycle A.C. Overall dimensions: 48″ long, 17″ wide, $8\frac{1}{4}$″ high. E.T.L. curve below.



These Units Represent Only a Part of the Complete Mitchell Commercial Line

MITCHELL MANUFACTURING COMPANY

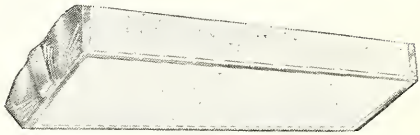
COMMERCIAL FLUORESCENT LUMINAIRES



No. 3004. Shielded Type Unit

Uses 4—40 Watt Lamps

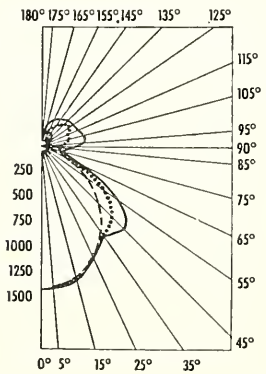
A carefully designed shielded type unit suitable for surface or suspension mounting, singly or in continuous rows. Designed for high lighting efficiency with minimum glare. All-steel construction throughout, with double-strength prismatic ribbed glass panels (readily removable for cleaning). End plates are of Satin Aluminum, designed to permit luminous translucent effect. Wireway channel (serves also as reflector) finished in white Baked Enamel. Abundant knockouts. Power factor over 90%. Stroboscopic corrected. Certified by E.T.L. and listed by Underwriters' Laboratories, Inc. Completely wired, ready to hang. For suspension mounting, unit requires Canopy and Stem Set 032ST. For 110–125 volts 60 cycle A.C. Overall dimensions: 48″ long, 17½″ wide, 6½″ high. E.T.L. curve below.

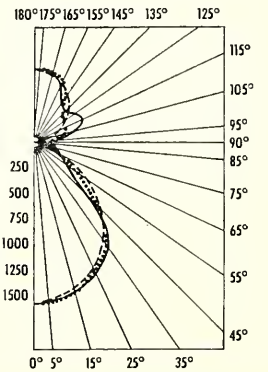


No. 3007 & 3008. DeLuxe Shielded Unit

Uses 4—40 Watt Lamps

Adaptable for suspension or surface mounting, singly or in rows. Uses double-strength ceramic treated glass side panels and prismatic ribbed glass bottom panel. Model No. 3008 has "Instant-Start" feature; no starters required. Both models have patented "One-man Quick-mount" feature. All-steel wireway channel and reflector, finished in white Baked Enamel. End plates of Satin Aluminum, with translucent luminous effect. Certified by E.T.L. and listed by Underwriters' Laboratories, Inc. Power factor over 90%. Stroboscopic corrected. Completely wired. For suspension mounting, unit requires Canopy and Stem Set 032ST. For 110–125 volts 60 cycle A.C. Overall dimensions: 48″ long, 17″ wide, 7⅜″ high. E.T.L. curve below.

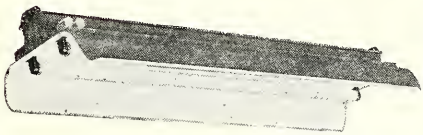




These Units Represent Only a Part of the Complete Mitchell Commercial Line

MITCHELL MANUFACTURING COMPANY

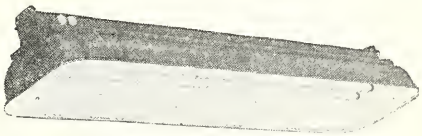
INDUSTRIAL FLUORESCENT FIXTURES



No. 2082. Open-End Reflector

Uses 2—40 Watt Lamps

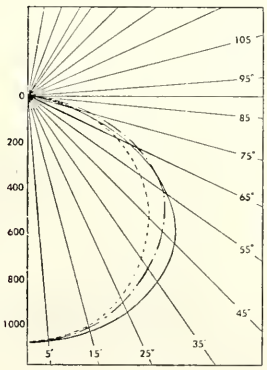
Designed for either individual or end-to-end continuous row mounting, suspension or direct ceiling mounting (see next page for wide range of mounting and hanging accessories). All-steel wireway channel and reflector. Reflector released instantly by means of patented "Instant-Latch". 4 models available. Choice of reflectors in either Baked Enamel or Porcelain Enamel. Nos. 2082 and 2084 have approved Tulamp Ballast, sockets, starters. Nos. 2083 and 2085 have "Instant-Start" Ballast; no starters required. Wired, ready to hang. Certified by E.T.L. and listed by Underwriters' Laboratories, Inc. Power factor over 90%. Stroboscopic corrected. For 110–125 volts 60 cycles A.C. Overall dimensions: 50″ long, $13\frac{3}{4}$″ wide, 7″ high. E.T.L. curve below.

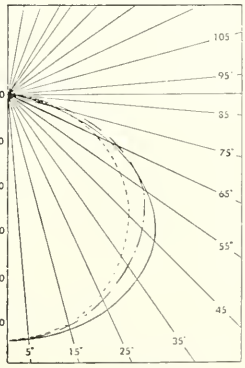


No. 2090. One-piece Closed-End Unit

Uses 2—40 Watt Lamps

Can be mounted individually or in continuous rows, directly to ceiling or suspended (see mounting accessories on next page). One-piece, closed-end all-steel reflector. Has patented "Instant-Latch" feature, which releases reflector instantly from chassis. 4 models available. Choice of reflectors in either Baked Enamel or Porcelain Enamel. Nos. 2090 and 2092 have approved Tulamp Ballast, sockets, starters. Nos. 2091 and 2093 have "Instant-Start" Ballasts; no starter switches needed. Completely wired, ready to hang. Certified by E.T.L and listed by Underwriters' Laboratories, Inc. Power factor over 90%. Stroboscopic corrected For 110–125 volts 60 cycle A.C. Overall dimensions: $52\frac{5}{8}$″ long, $13\frac{3}{8}$″ wide, $7\frac{3}{16}$″ high. E.T.L. curve below.





These Units Represent Only a Part of the Complete Mitchell Industrial Line

MITCHELL MANUFACTURING COMPANY

ACCESSORIES FOR MOUNTING OR HANGING MITCHELL INDUSTRIAL FIXTURES

The accessory fittings illustrated and described below, are available for every conceivable modern method of mounting or hanging MITCHELL fixtures. Illustrations on next page show the complete versatility of MITCHELL Industrial Fixture design and methods for employing the wide variety of available mounting and hanging accessories.



Part No. 316—Channel Coupler for open end reflectors.



Part No. 314—Messenger Cable Hanger.



Part No. 315—Slide Hanger Clamp, with nut and bolt.

Part No. 306—Rod. 3′ long, ⅜″ diam. threaded both ends.



Part No. 318 Aligner Strap.

Part No. 312—Stem Set (Canopy and ⅜″ I.P. Stem).



Part No. 317—Channel Coupler for closed end reflectors.



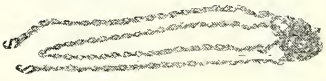
Part No. 311 Pull Switch with Pull Chain.



Part No. 301—U. L. Approved Cord and Plug Set (6½′ long) with ground lead and bushing.



Part No. 313—Two-conductor Cord and Plug (5½′ long) with bushing.



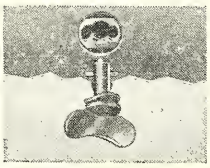
Part No. 302—Pair of 8′ Tenso Chains with "S" Hooks. (Chains 7/0 Tenso—175 lb. torque.)

DESIGNED FOR EASY INSTALLATION AND SERVICING

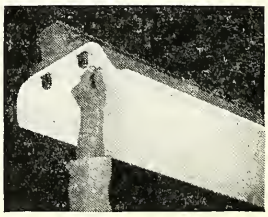
Simplified channel and easy-fit accessories reduce mounting time and effort. "Instant-Latch" feature permits quick removal of reflector for easy cleaning. All parts are readily accessible.



Reflector instantly released by quarter turn of "Instant-Latch."



"INSTANT-LATCH"—Mitchell's aircraft engineered "Instant-Latch," a strong cam-type fastener secured on reflector, speeds cleaning and servicing. Two latches on each reflector.



Reflector fastened back to chassis by quarter turn of "Instant-Latch"

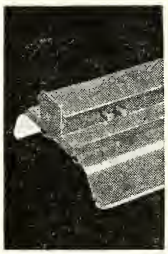
MITCHELL MANUFACTURING COMPANY

METHODS FOR MOUNTING OR HANGING INDUSTRIAL UNITS



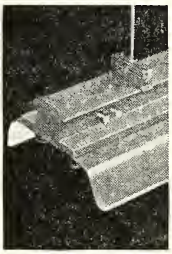
CHAIN SUSPENSION (*With Cord and Plug*)

All units—open end or closed end—may be hung with chains. "S" hooks fit securely into holes of flange on end piece.



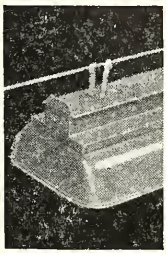
SURFACE MOUNTING

Bolt through small knockouts at end of channel. For continuous rows, use pipe separators 1″ long over mounting bolts.



ROD SUSPENSION

Rod (⅜″ diam.) is held securely to Slide Hanger Clamp by threaded nut, top and bottom. Knockouts provided for wiring to outlet.



MESSENGER CABLE

For messenger cable suspension, use Messenger Cable Hanger No. 314. Mount directly to channel or to Slide Hanger Clamp.



PULL SWITCH

For individual mounting, Switches with pull-chain can be furnished for individual switching, completely installed as illustrated.



I.P. STEM MOUNTING WITH CANOPY

For office or drafting room, I.P. Stem and Canopy are available. Stem is mounted directly to wireway channel, secured with lock-nuts.





CONTINUOUS ROWS

Closed-end or open-end units are joined end-to-end by use of Channel Couplers No. 316 or No. 317 shown at left. Units may be surface-mounted directly to ceiling, bolting through small knockouts; or they may be suspension-mounted, by use of chains, conduit or rods.

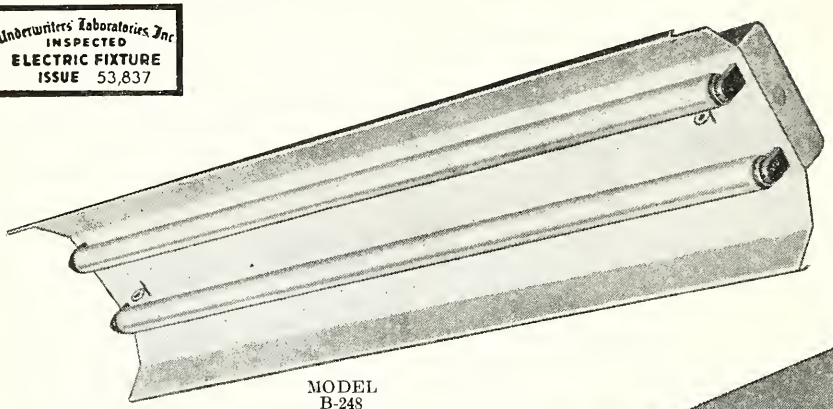
MITCHELL CATALOGS AVAILABLE ON REQUEST

The MITCHELL fixtures described on these pages represent only a partial listing of the MITCHELL Commercial and Industrial fixtures which are available. For information covering the complete line of MITCHELL Commercial Fluorescent Fixtures, write for Catalog No. 285. For data on the complete line of MITCHELL Industrial Fluorescent Units, write for Catalog No. 281. For information on both Commercial and Industrial Fixtures, ask for combined Catalog No. 286.

MODERN LIGHT & EQUIPMENT CO.

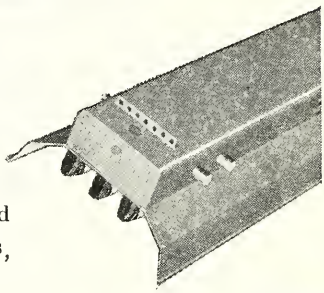
3812 South Wabash Ave., Chicago 15, Ill.

Underwriters' Laboratories, Inc.
INSPECTED
ELECTRIC FIXTURE
ISSUE 53,837



MODEL
B-248

MODERN-LITE
INDUSTRIAL FLUORESCENT UNIT



MODEL
B-348

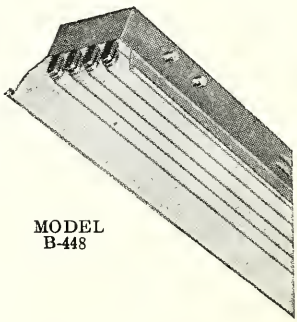
Designed for general illumination or for localized lighting over machines, work benches, assembly lines, etc.

Reflector is drawn from a single sheet of heavy gauge steel to meet all Underwriters' specifications. Finished in French Gray outside, with white Porcelite Baked Enamel inside.

Fitted with renewable starters and approved ballasts. Reflectors on Models B-248 and B-348 are held to the top housings by means of two captive spring tension latches. Wiring and all other parts of the fixture are readily accessible.

Housing is fitted with seven-hole bracket at either end for straight or asymetric hanging; also with knockouts for rigid or stem mounting.

For single or continuous row mounting.



MODEL
B-448

SPECIFICATIONS

Model No.	No. of Lamps	Lamp Size	FIXTURE			Approx. Ship. Wt.	Line Voltage	Ballast Power Factor
			Long	Wide	High			
B-248	2	48"-40W	48"	12"	6¼"	25 Lbs.	110-125	95-100%
B-348	3	48"-40W	48"	12"	6¼"	29 Lbs.	110-125	95-100%
B-448	4	48"-40W	48"	14"	6¼"	36 Lbs.	110-125	95-100%

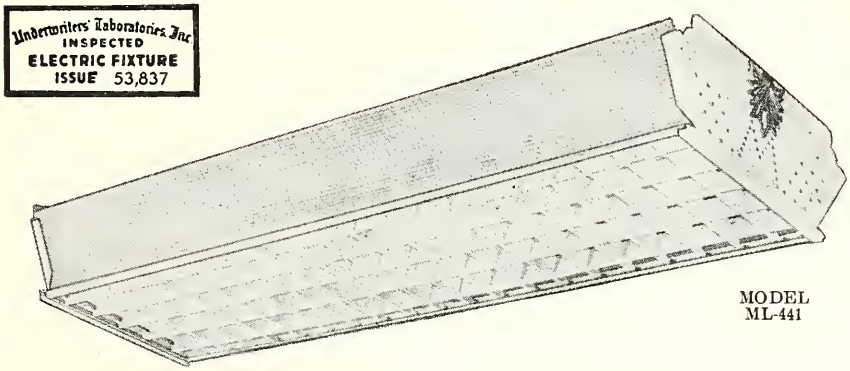
B-248 and B-448 can be furnished with instant start.
Available for use with 220-250 volt current 60 cycle AC operation at no additional cost.

Complete Catalog of Industrial & Commercial Units on Request

MODERN LIGHT & EQUIPMENT CO.

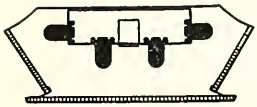
3812 South Wabash Ave., Chicago 15, Illinois

Underwriters' Laboratories, Inc.
INSPECTED
ELECTRIC FIXTURE
ISSUE 53,837

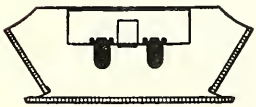


MODEL
ML-441

DIFFUSE-O-LITE
COMMERCIAL FLUORESCENT UNIT



4-LAMP ARRANGEMENT



2-LAMP ARRANGEMENT

Union Made

All fabricating, assembling, wiring, spraying and packing of Modern-Lite Fluorescent Fixtures is done by members of The International Brotherhood of Electrical Workers, A. F. of L.

Box type metal louver bottom diffusion panel and translucent ribbed glass side panels.

Two or four lamp arrangement with large reflector area. Reflector and the bottom diffusion panel finished in white Porcelite Baked Enamel.

Bottom louver and side diffusion panels removable for cleaning or servicing by sliding them out of the metal frame; no bolts or screws.

Equipped with renewable starters and approved two-lamp ballasts. End and divider plates are provided with knockouts for continuous wiring; equipped for surface, stem or continuous row mounting.

Hand hole and heavy iron strap are provided for surface mounting; also knockouts for stem mounting with threaded stem support flanges inside the housing.

SPECIFICATIONS

Model No.	Mounting	No. of Lamps	Lamp Size	FIXTURE			Approx Ship. Wt	Line Voltage	Approx. Powr. Fctr.
				Long	Wide	High			
ML-441	Surface	4	48"—40W	48"	16"	6½"	57 Lbs.	110-125	95-100%
ML-440	Stem	4	48"—40W	48"	16"	6½"	62 Lbs.	110-125	95-100%
ML-241	Surface	2	48"—40W	48"	16"	6½"	46 Lbs.	110-125	95-100%
ML-240	Stem	2	48"—40W	48"	16"	6½"	51 Lbs.	110-125	95-100%

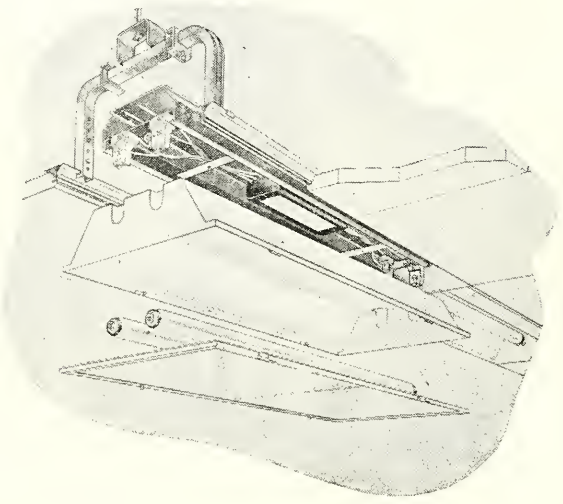
Available with instant start.
Available for use with 220-250 volt current 60 cycle AC operation at no additional cost.

Complete Catalog of Commercial & Industrial Units on Request

THE MILLER COMPANY

99 Center Street
Meriden, Conn.

Miller Lighting Service Is All-Inclusive.
In the Miller line are continuous wireway fluorescent lighting systems for stores, offices, schools, factories and public buildings. And its incandescent and Mercury Vapor reflector equipment, lighting glassware and fixtures have broad industrial and commercial application.



THE MILLER FLUORESCENT TROFFER LIGHTING SYSTEM provides light at the overall level desired, and in addition, it can be installed as single units, blocks, geometric patterns or light strips to form any ceiling pattern desired . . . CEILINGS UNLIMITED.

Designed as a **COMPLETE LIGHTING SYSTEM**, the wired channels provide a rigid, continuous wireway, eliminating the need for a high percentage of conduit, fittings, etc. Channels are constructed with flanged tops so that supporting brackets may be readily attached at any point along their entire length.

Applicable with ceiling surfaces of plaster, unit panels, or acoustical tiles, the use of Miller Troffers gives complete freedom in the selection of ceiling material best suited for individual requirements.

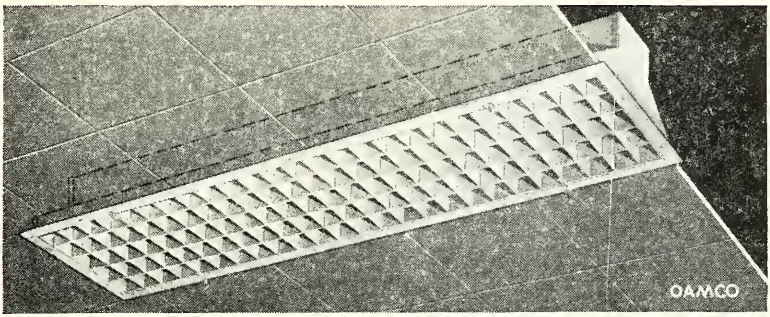
OVERBAGH & AYRES MFG. CO.

411 So. Clinton Street

Chicago 7, Illinois

OAMCO REFLECTORS

FLUORESCENT FIXTURES & INCANDESCENT REFLECTORS FOR INDUSTRIAL AND COMMERCIAL USES



OAMCO fluorescent fixtures for recessed mounting are available in the open type or with diffusing glass or an egg crate louver. The open type fixture is furnished with or without a center baffle: the baffle is 2⅜" high running the entire length of the fixture to provide a 45 degree concealment normal to the lamp. The glass bottom fixture can be furnished with ribbed or fluted panels or with Flur-O-Guide lens. The egg crate louver fixture provides a 45 degree normal and 30 degree parallel concealment to the lamp: louver is attached to the fixture by means of hooks.

Fixtures are made of steel, finished grey outside, white plastic enamel inside. The inner or reflecting surface has a mean reflection factor of not less than 82%. The design of the fixture is such that the mean light output of the complete unit is 76% or more of the combined lamp outputs.

Fixtures are made for continuous rows or individual mounting and are furnished wired including lampholders, starters and high power factor ballasts.

All Illumination data from tests by Company Laboratory

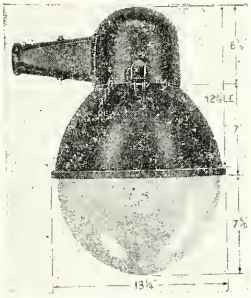
PHILADELPHIA ELECTRICAL & MFG. CO.

1200-36 North 31st Street

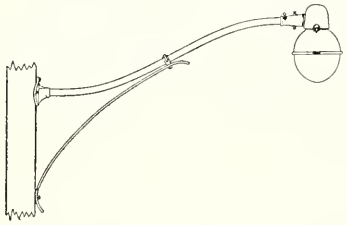
Philadelphia 21, Pa.

Sales Offices in all Principal Cities.

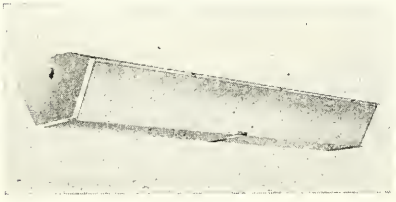
PEMCO STREET & HIGHWAY LIGHTING—SERVICE STATION LIGHTING
COMMERCIAL & INDUSTRIAL FLUORESCENT LIGHTING
FLOOD LIGHTING



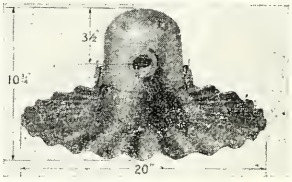
813S4114 Luminaire with 1¼" slip fitter for internal wiring. Available also for external wiring. Flashover 25 KV. Can be furnished for symmetric, asymmetric or 2-way distribution. Other types include top entrance Hoods for internal or external wiring, wet process porcelain insulators, and Hoods equipped with Brackets for wall or wood pole mounting.



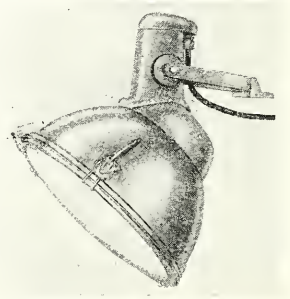
870 Upsweep Bracket Arm. Upsweep Brackets are available in 4, 6, 8, 10 and 12′ lengths in 1¼, 1½ and 2″ pipe sizes. Straight Brackets and Mast Arms also available in a variety of lengths 3′6″ to 16′.



GZ 448 Fluorescent Lighting Unit. A four lamp commercial unit with rugged steel body and Corning "Alba-Lite" glass panels. For flush or stem mounting. Other industrial and commercial fluorescent units available.



619S211 Luminaire. Side entrance aluminum Hood tapped 1½" with 20" Radial Wave Reflector. A variety of Radial Reflector Fixtures are available with top entrance Hoods, Wet or Dry Process Porcelain Insulators, for internal or external wiring.



8010 Floodlight. An 18" Floodlight available with either alzak or diffused reflecting surface. Hinged lens door that will accommodate type lenses for beam control. Furnished for either pole or crossarm mounting. Information on other types of Floodlights on request.



5001 Assembly consisting of Mushroom Type Luminaire with spot or flood light mounted on top. Spot or flood light is designed for the PAR38—150 watt sealed beam lamp. Available also with 2, 3 or 4 Units mounted on the Mushroom Light, 1, 2, 3 or 4 Units mounted on a 2" slip fitter, or 1, 2, 3 or 4 Units mounted with ½" pipe tap. Ruggedly designed for outside use.

THE PHOENIX GLASS CO.

Monaca, Pa.

NEW YORK - CHICAGO LOS ANGELES - ATLANTA - DALLAS - WINNIPEG

"Phoenix - Quality"

PHOENIX 6653
FOR CORRECT SEMI-INDIRECT LIGHTING

PHOENIX-6653 typifies the finest in semi-indirect lighting equipment. The conical bowl has beauty and modern simplicity. Dense white Sterling glass provides a flood of uniform subdued light, free from objectionable glare, at high foot candle level.

Semi-indirect lighting combines the best characteristics of direct and indirect illumination. This type of lighting provides uniformly distributed illumination which assists in maintaining the low brightness conducive to seeing comfort and visual efficiency.

PHOTOMETRIC DATA

The photometric test made by The Electrical Testing Laboratories shows a total light output of 86%. Of this amount 90% is directed upward to the ceiling and only 10% filters through No. 6653. The ceiling becomes a secondary light source to provide a flood of shadowless and glareless lighting.

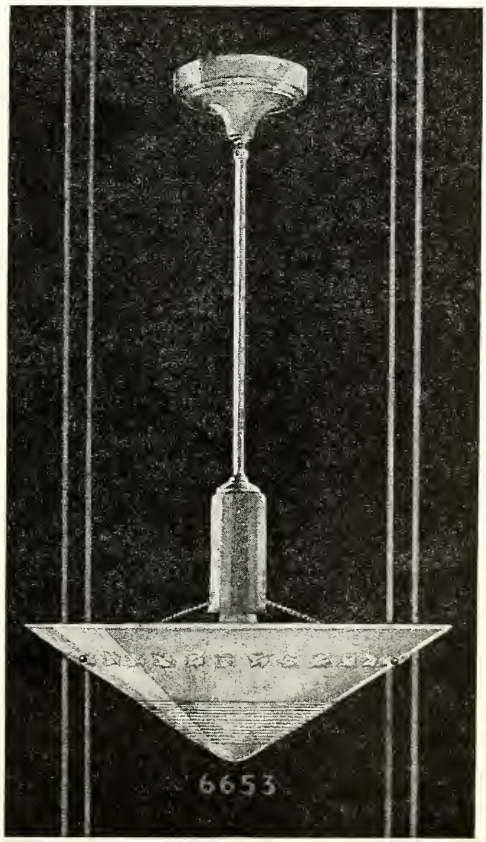
ZONE	Per Cent Total Lumens Bare Lamp	Total Per Cent Light Output
0–60°	5.5	
0–90° (Downward)	8.0	
90–180° (Upward)	78.0	86%
0–180°	86	

WE RECOMMEND

Ceiling finish Mat White. Wall Finish light Tan or Green.

Sizes Available

14″ 150 Watts
16″ 200 Watts
18″ 300–500 Watts
22″ 750–1000 Watts



M-117

PITTSBURGH REFLECTOR COMPANY

Home office—Oliver Building, Pittsburgh 22, Pa.

There is a Pittsburgh Permaflector Lighting Unit for every commercial, institutional and industrial application, whether you need fluorescent or incandescent lighting or a combination of both.

"Pittsburgh" Permaflector

BRANCH OFFICES

CHICAGO 3, ILL.
R. O. Williams, Mgr.
37 S. Wabash Ave.

SEATTLE 1, WASH.
Lyman D. Morgan
1012 Securities Bldg.

NEW YORK 19, NEW YORK
Pittsburgh Reflector Co.
1775 Broadway

FACTORY REPRESENTATIVES

ATLANTA 3, GA.
M. L. Whitman
Bona Allen Bldg.

BALTIMORE 17, MD.
W. B. Masland Co.
625 W. North Ave.

BIRMINGHAM 3, ALA.
E. B. Richey
Comer Bldg.

BROOKLINE 46, MASS.
Detweiler-Bell Co.
60 Dwight St.

BUFFALO, N. Y.
H. H. Mallon
308 Morgan Bldg.

CHARLOTTE, N. C. 2,
E. Dempsey Jones
121 E. 3rd St.

CINCINNATI, 13, OHIO
J. F. Voelker
2650 Cedarbrook Dr.

CLEVELAND 14, OHIO
Handel-Davies Co.
686 Union Commerce Bldg.

DALLAS, TEXAS
Frank Peabody
Santa Fe Bldg. Unit 2

DENVER 2, COLORADO
P. A. Douden
1645 Wazee St.

DES MOINES 9, IOWA
Delavan Engineering Co.
414 Twelfth St.

INDIANAPOLIS 4, IND.
Scott-Jaqua Co.
Indiana Terminal Warehouse

JACKSON, MISS.
Chilton & Chilton
4126 N. State St.

KANSAS CITY 6, MO.
H. M. Curfman
946 New York Life Bldg.

LOS ANGELES 21, CALIF.
F. E. Hastings
2045 E. 7th Street

MEXICO CITY, MEXICO
D. F. Jose Goy
Apartado 2724

MIAMI BEACH, FLA.
F. E. Lott
33 Venetian Way, Apt. 77

MILWAUKEE, WIS.
Joe Sabater
1737 Edron St.

MINNEAPOLIS 2, MINN.
Balch Sales Co.
200 Baker Bldg.

MONTREAL, QUE., CANADA
H. P. M. Carter
102 Willowdale Ave.

NEW YORK 17, N. Y.
Brannin & Kelly
551 Fifth Ave.

PHILADELPHIA 6, PA.
Hopkin Bros.
120 N. 7th St.

SALT LAKE CITY 1, UTAH
R. Ackerman
318 Dooly Block

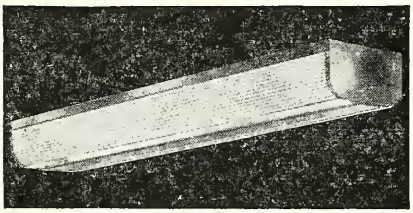
SAN FRANCISCO 3, CALIF.
F. M. Nicholas Co.
1123 Harrison St.

ST. LOUIS 8, MO.
L. L. Burress
Melbourne Hotel

WASHINGTON, D. C.
Sam Masland
410 Bond Bldg.

WINNIPEG, MANITOBA
Cochrane-Stephenson Co.
401 Ryan Bldg.

Pittsburgh Permaflector Fluorescent Luminaire—*"The Jefferson"*

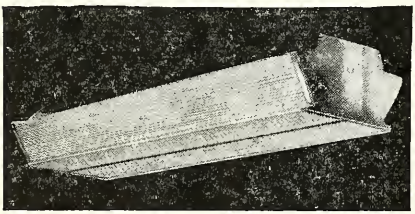


The distinctive appearance of "The Jefferson" is enhanced by curved Skytex Satinol glass panels. Available as "The Tyler" (A-7240, etc.) with hinged egg crate louver bottom.

Number	Lamps	Length	Width	Depth	Sh. Wt.
A-1240	2—40 W.	48⅛"	10⅞"	5⅞"	38 lbs.
A-1340	3—40 W.	48⅛"	10⅞"	5⅞"	42 lbs.
A-1440	4—40 W.	48⅛"	14"	5⅞"	51 lbs.

Surface mounted or suspension mounted with Hanger No. AH-201, individually or in continuous row.

Pittsburgh Permaflector Fluorescent Luminaire—*"The Van Buren"*

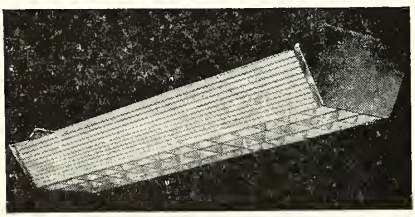


Contrasting side panels of Skytex Satinol glass and ribbed Skytex clear glass bottom panels give this unit sparkling and efficient beauty.

Number	Lamps	Length	Width	Depth	Sh. Wt
A-2240	2—40 W.	48⅛"	15⅞"	7¾"	62 lbs.
A-2340	3—40 W.	48⅛"	15⅞"	7¾"	66 lbs.
A-2440	4—40 W.	48⅛"	15⅞"	7¾"	64 lbs.

Surface mounted or suspension mounted with Hanger No. AH-201 individually or in continuous row.

Pittsburgh Permaflector Fluorescent Luminaire—*"The Wilson"*



Iridescent Linex Satinol glass side panels and fully hinged egg-crate louver bottom assure well shielded and efficient illumination as well as easy accessibility.

Number	Lamps	Length	Width	Depth	Sh. Wt.
A-4240	2—40 W.	48⅛"	15⅞"	7¾"	46 lbs.
A-4340	3—40 W.	48⅛"	15⅞"	7¾"	50 lbs.
A-4440	4—40 W.	48⅛"	15⅞"	7¾"	56 lbs.

Surface mounted or suspension mounted with Hanger No. AH-201, individually or in continuous row.

"Pittsburgh" Permaflector

Fluorescent Units are furnished complete with FS-4 Starters for 110–125 volt, 60 cycle current or 220–250 volt, 60 cycle current. No lamps provided. Units are available for 50 cycle current at additional cost; No-Blink Starters at additional cost.

PITTSBURGH REFLECTOR COMPANY

Home office—Oliver Building, Pittsburgh 22, Pa.

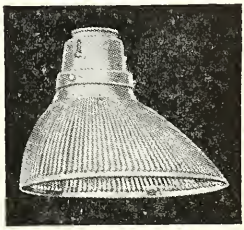
PERMAFLECTOR LUMINAIRE NO. N-592-C

This luminaire is predominately indirect, but a portion of its light is directed downward through the louvered bottom. This louver-type unit is used in installation requiring secondary direct illumination. It is spun of heavy-gauge, first quality sheet aluminum. An efficient Permaflector controls the light distribution. Bowl—21″ diameter. This indirect unit, with direct component, is one of a series available in 300–500-watt and 750–1000-watt mogul-base lamp sizes. Other units are available in 750 and 1000-watt medium bi-post lamp sizes.



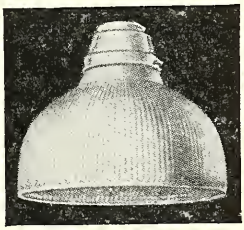
SHOW WINDOW PERMAFLECTOR NO. 54 SERIES

The No. 54 Series are designed primarily for shallow windows 7′ to 10′ high; medium trim; island windows; or windows with upper background portion of glass. They are also suitable for display lighting of rug racks, stock-quotation boards, fronts and entrances, choirs and sanctuaries, handball, squash, indoor badminton and tennis courts, art galleries and museums. Lamp sizes: 150-watt PS-25 and 200-watt PS-30. This series may be external or recessed mounted.



RECESSED PERMAFLECTOR NO. E-230 SERIES

This series of recessed combinations provides a broadly distributing reflector with a desirable center concentration. They are used for down-lighting in stores, handball courts, gymnasiums, badminton courts and below magazine floors and other locations with low head room. Equipped with Permaflector E-230 Outlet Box Cover and flush mounting ring. Lamp Sizes: 300-watt PS-35 medium base, 200-watt PS-30 or 150-watt PS-25.



PERMAFLECTOR FLOODLIGHTS NO. ST SERIES

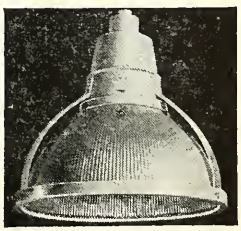
Weather-proof Permaflector enclosed floodlights are ready to install. Units are complete with: silver-mirrored glass reflector, convex heat-resisting cover glass lens.

Cat. No.	Lens Diameter	Wattage	Base	Beam Spread	Permaflector Number
ST-200	8⅜″	200	Medium	50°	C-101-GO
ST-500	15¾″	500–300	Mogul	40°	C-500-GO
ST-530	15¾″	500–300	Mogul	170°	E-530-GO
ST-1010	18¾″	1000–750	Mogul	106°	I-1005-GO
ST-1050	18¾″	500–300	Mogul	106°	I-1005-GO
ST-1110	18¾″	1000–750	Mogul	46°	F-1001
ST-1150	18¾″	500–300	Mogul	49°	F-1001



PERMAFLECTOR INDUSTRIAL UNIT NO. I-1005-N

To provide support and protection for the Permaflector, without the use of a complete housing, we offer the I-1005-N incorporating the retaining ring arrangement, for lighting interiors, in industrial plants, auto repair shops, airplane hangars, armories, power plants and similar installations. Available in concentrated and broad light distribution; wattages from 150 to 1000-watts and for use with 400-watt mercury lamps. Bottom diameter 16¼″.



CONSULT YOUR NEAREST PITTSBURGH PERMAFLECTOR REPRESENTATIVE FOR ADDITIONAL DATA

"Pittsburgh" Permaflector

RAILLEY CORPORATION

2910 Taft Avenue, Cleveland 8, Ohio

61 W. 55th St.
New York 19, N. Y.

12-113 Merchandise Mart
Chicago, Illinois

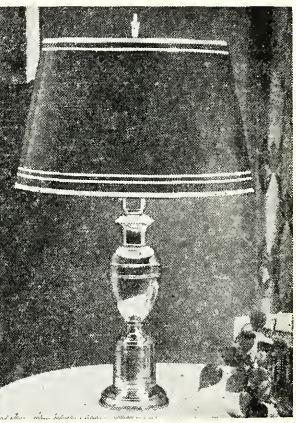
Other offices in Detroit, Denver, San Francisco and other principal cities

Railley Corporation, originator of the Pin-It-Up Lamp, and maker of a complete line of Table and Pin-to-Wall Lamps has pioneered several recent developments in portable lamp design. These include the *Deep-Set Socket* which lowers the light source, thus giving a greater light intensity over a wider area, the *Inverted Socket* which accomplishes a similar effect at lower cost, and the luminous *Glo-Switch*, easily found without fumbling in the dark. Most recent additions are the two Certified Lamps described below.

Certified END TABLE LAMP

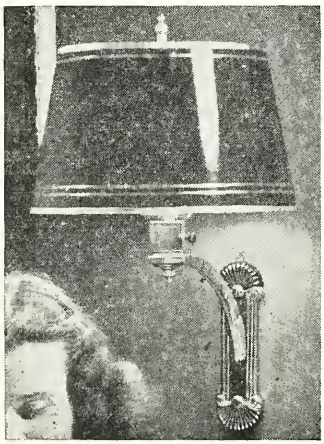
This new Railley Table Lamp has met the 105 distinct specifications for Certified Lamps, covering construction, safe, trouble-free wire, prevention of excessive heat, noise, etc., and protection of eyes from glare.

The lamp base and husk are either polished natural brass or brass with satiny bronze finish. The Certified Shade is sturdy parchment paper, of Maroon, Forest Green or Ivory, accented by narrow gold foil stripes.





Height 25″. Reflector design "C". Certified Switch for multiple-filament bulb, 50–100–150 watt (medium base). Provides average of 20 footcandles on reading surface.



Certified PIN-IT-UP* LAMP

This new Pin-It-Up Lamp also meets Certified Lamp specifications. The lamp bracket is of enameled metal, in ivory, maroon or green, with arm, husk and decorative columns on panel of polished brass.

Shade of ivory, maroon or green, similar to table lamp shade, but slightly smaller, to fit Reflector design "B". Uses 50–100–150 watt multiple-filament bulb.

This lamp averages 20 footcandles on the reading surface, for casual reading and writing, or for general utility lighting purposes.

Note: It should be mounted on wall so that bottom edge of shade is 48″ from floor.

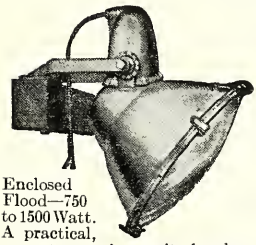


* *Reg. U.S. Pat. Off.*

REVERE ELECTRIC MANUFACTURING CO.

6009-17 Broadway, Chicago, 40, Ill.

Manufacturers of
SERVICE STATION • SPORTS • AIRPORT • INDUSTRIAL
AND MARINE LIGHTING EQUIPMENT

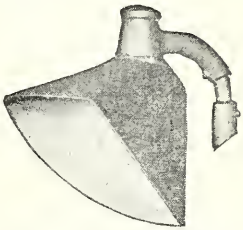


Enclosed Flood—750 to 1500 Watt. A practical, easy to service unit for long range lighting.

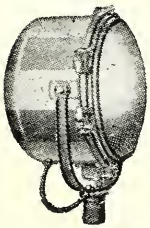
Revere ELECTRIC MFG. CO. CHICAGO, U.S.A.

The Complete Quality line is the result of many years of specialization.

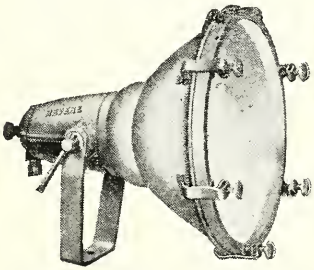
We offer open and enclosed floods for every purpose. High and low mounting Lighting Standards, Hinged Floodlight Poles, Sign Standards, etc.



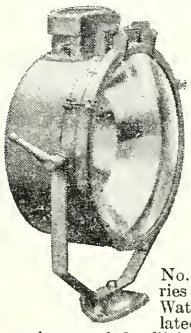
Revere Triangular, the only floodlight made that casts a definite 90° beam pattern.



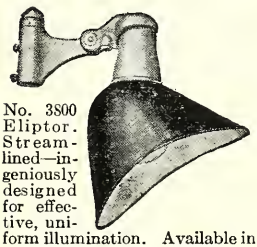
Airport Floodlights. 12", 18", 24" lens sizes. Masterpieces in design and construction.



Open and Enclosed Floods. A unique line in 150 to 1000 Watt sizes for any type of mounting. Also portable models.

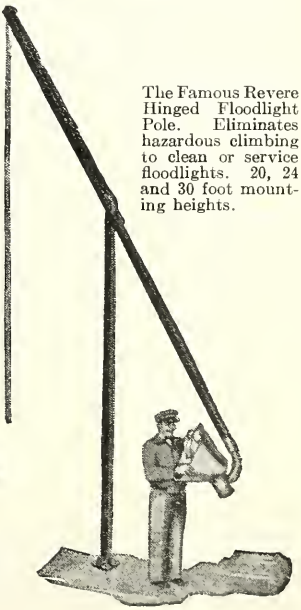


No. 6500 Series 750–1000 Watt ventilated and weather-proof floodlight.



No. 3800 Eliptor. Streamlined—ingeniously designed for effective, uniform illumination. Available in a variety of colors.

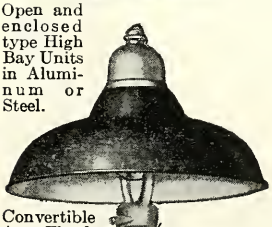
Write for Catalog Data



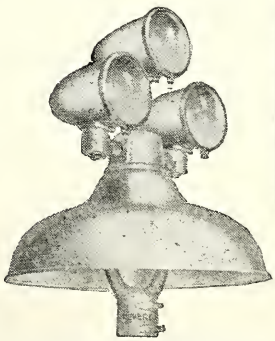
The Famous Revere Hinged Floodlight Pole. Eliminates hazardous climbing to clean or service floodlights. 20, 24 and 30 foot mounting heights.



Open and enclosed type High Bay Units in Aluminum or Steel.



Convertible Area Flood, in all aluminum or any porcelain enamel color. Weather-proof accommodates one, two or three top floods.



No. 3650-S, in all aluminum or colored porcelain enamel. Does a fine area lighting job plus spot-lighting.

RAMBUSCH

40 West 13th Street, New York 11, N. Y.

DOWNLITES



Library, College of the City of New York. Downlighting from 16 1000-Watt Rambusch Downlites.



Rambusch Downlite
Reg. U. S. Patent Office
Approved by Underwriters up to 1000-Watt for fireproof, 750-Watt for non-fireproof construction.

RAMBUSCH DOWNLITES are suitable for use in lofty interiors, producing efficient illumination on the horizontal plane—in an inconspicuous manner.

PRINCIPAL FEATURES OF RAMBUSCH DOWNLITES:

1. The small ceiling aperture is inconspicuous, and emits no light beyond 45°. All spill light is trapped in annular baffles above aperture.
2. Standard "General Service" lamps are used exclusively.
3. Simple to install and maintain, from above or below.
4. Sturdy all metal construction.
5. Fixed focus reflectors insure predictable performance.
6. High beam efficiency. Minimum utilization factor 30% regardless of room index. (ETL Test Report #148667.)
7. Alzak reflectors, standard. Gold reflectors when specified.

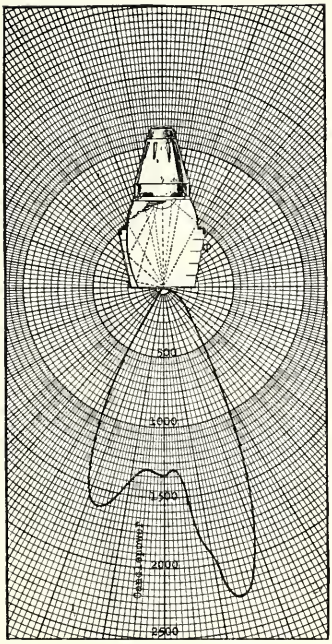
DIMENSIONS

Type Downlite	Wattage	Height	Max. Body Diam.	Lower Body Diam.	Ceiling Aperture Diam.	Net Weight
Medium	200- 300	20½″	11″	8″	5″	13 lbs.
Mogul	300- 500	27″	14½″	11″	6″	25 lbs.
Bipost	750-1000	31″	14½″	11″	6″	26 lbs.

Gold reflectors are recommended where decorative quality is important. Efficiency reduced about 20%. Special mounting arrangements for slanting ceilings, rosettes, etc., manufactured to fit requirements.

RAMBUSCH

DOWNLITES



Vertical Candlepower Distribution

Right—200-Watt Rambusch Shovel Downlite. 42% light output.

Left—200-Watt Rambusch Downlite. 31% light output.

Electrical Testing Laboratories Report No. 148667.

According to the nature of the seeing tasks, downlighting should be furnished for single, double, or triple beam coverage of the area to be lighted. Single coverage is recommended only where strict economy is necessary and critical seeing is not essential. Double coverage is recommended for Churches, Auditoriums, Public Buildings and triple coverage or better for all installations involving critical seeing, such as Banks, Libraries and Offices. Often the number of Downlites to be used is indicated or even dictated by architectural considerations, such as architectural bays, rosettes and coffers.

The approximate number and wattage of Rambusch Downlites required for a given application may be determined through the following formulas:

Approximate number of Downlites required, n,

For single beam coverage $n = 1.25 \left(\frac{a}{h^2}\right)$(1)

Where a = area to be downlighted, h^2 = square of the distance from working plane to Downlite.

Double, triple, or quadruple coverages are determined by multiplying by 2, 3, or 4. Spacing of Downlites should be as uniform as the building construction will permit.

Having determined the number, n, the wattage of each individual Downlite may now be established through the following formula:

Wattage per Downlite, $Wdl = (0.182) \left(\frac{I \times a}{m \times N}\right)$ (2)

Where I = Desired footcandles on working plane in service.

a = Total area to be downlighted.

m = Maintenance factor. Normally .75.

Wdl = should be reconciled to nearest available standard lamp. (Formulas are based on the average lumen output of 300 to 1000-Watt standard inside-frosted General Service lamps).

For pleasing effect we recommend supplementing the downlighting installation with a small amount of general or indirect light.

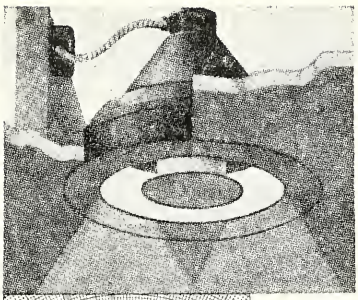
Our Engineering Department will gladly look over your proposed layout and give you the benefit of its experience in the planning of Downlite installations.

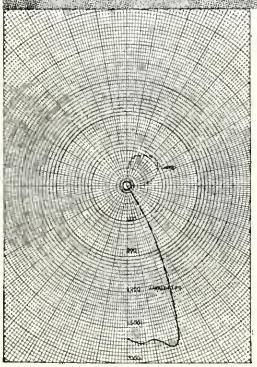
Where, in addition to Downlighting it is desired to illuminate an adjacent wall, this can be accomplished by mounting an auxiliary "shovel" reflector inside the Downlite. See distribution curve above.



At left—Unretouched photograph showing light from Downlites falling on chairs and lower walls, and light from "shovel" reflectors falling on mural painting. Note that the light pattern reaches to within an inch or so of the ceiling in spite of aperture being flush with ceiling.

RAMBUSCH
ANNULITES





Polar distribution from 150-Watt Annulite. Light output 54% of silver bowl lamp. From Electrical Testing Lab. Report No. 150,580.



Annulite installed in private dining room. Eugene & Lee Schoen, Architects, New York, N. Y

For Simplified Method of specifying number and wattage of ANNULITES, see preceding page, formulas (1) and (2). In place of multiplying factor of 0.182 (formula 2), use 0.111. For uniform lighting, spacing should not exceed .75h (h = distance from working plane to unit).

Like RAMBUSCH DOWNLITES (see preceding page), ANNULITES are all-metal, precision-built, especially suitable for locations where soft downlighting is desired and where space for recessing is limited. The main features are:

1. The unusual annular (ring-shaped) aperture permits complete concealment of lamp and reflector brightness beyond the 45° sightline.
2. The vertical inside walls may be colored to customer's specification.
3. Utilize standard silver bowl lamps.
4. Easy installation and maintenance from below or above.
5. All parts are metal.
6. Fixed focus, precision reflectors, predictable performance.
7. Beam efficiency over 50% (ETL Test Report #150,580).
8. Reflectors are Alzak Aluminum for white light. Gold reflectors for soft, warm light.

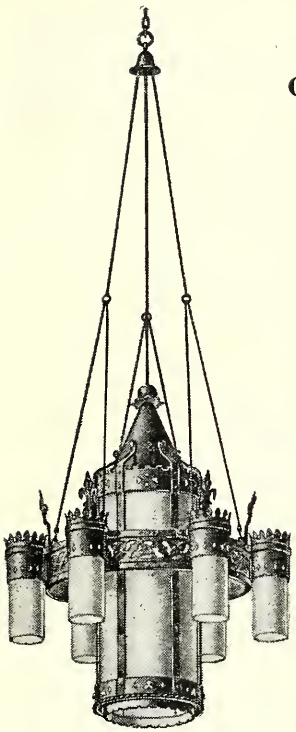
DIMENSIONS

Wattage	Catalog No.	Diameter of Body	Height Overall	Diameter of Flange
60	AL-47	$9\frac{1}{2}''$	$7''$	$11\frac{3}{4}''$
100	AL-48	$9\frac{1}{2}''$	$8\frac{1}{4}''$	$11\frac{3}{4}''$
150	AL-49	$11\frac{3}{4}''$	$9\frac{1}{4}''$	$13\frac{1}{2}''$
200	AL-50	$13\frac{3}{4}''$	$10\frac{1}{2}''$	$16''$
300	AL-52	$16''$	$12\frac{1}{2}''$	$18\frac{1}{2}''$

ANNULITE specifications should include desired color of inner vertical walls as well as reflector color—white or golden. The ANNULITE principle is not limited to the recessed fixture form, but is adaptable to cases where partially recessed, surface mounted, or suspended fixtures are desirable. In such instances, the ANNULITE body is incorporated in a housing designed to harmonize with the general decorative motif.

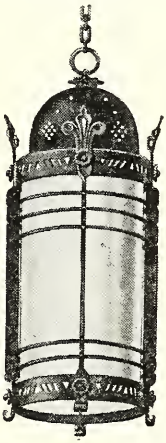
RAMBUSCH

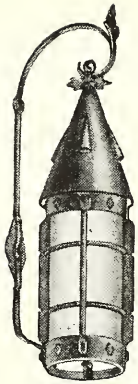
CHURCH LIGHTING



CORONA UNIT No. G-174
Overall Height 8¼".
Overall Width 3¼".
Diameter of Glass 4½" and 12".

NAVE LANTERN
No. R-43
Overall Height 31". Overall Width 12".
Diameter of Glass 10".



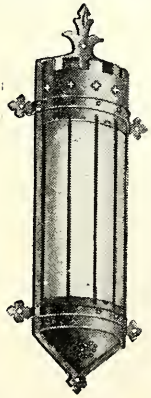


OUTSIDE LANTERN
No. O-110
Overall Height 31".
Maximum Projection 11".
Diameter of Glass 6".



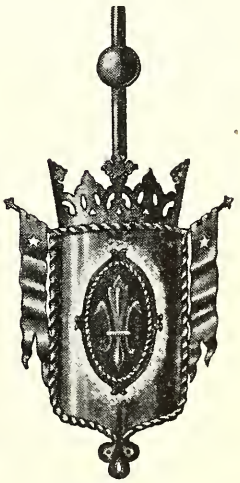
CEILING FIXTURE
No. C-62
Overall Height 6½".
Extreme Diameter 13".
Diameter of Glass 12".

BRACKET FIXTURE
No. BR-73
Overall Height 36".
Maximum Width 13".
Diameter of Glass 8".



Any form of architectural lighting, church lighting, not the least, must be planned with utmost consideration for the artistic, the psychological, as well as the engineering phases. Rambusch Designers and Engineers will gladly give you the benefit of their extensive experience in these fields. On this page will be seen a few church lighting fixtures typical of Rambusch designs. Hundreds more are available, or we will create designs for any specific interior or exterior. In addition, we have prepared a booklet, "Church Lighting Trends" which, together with our "Church Lighting Questionnaire" will be sent upon request.

On receipt of plans or measures with photographs of your church, we will send you a comprehensive proposal including sketches and layouts.



SANCTUARY REFLECTOR
No SR-46
Overall Height 34".
Overall Width 16".
2 Circuits.

S&M LAMP CO.

119 W. 36th Place — Los Angeles 54, Calif.

"SINCE 1909"

AIA File 31F23 & 24

"Red Cap" Aluminum Flood-Lites

Alzak* Processed

APPLICATIONS

Recreational	Industrial	Commercial
Residential	Construction	Emergency
Advertising	Protection	Portable
Outdoor Sales	Black Light	Storage
Photography	Mercury Vapor	Animal Husbandry

TYPES

Weatherproof — Semi-weatherproof — Open

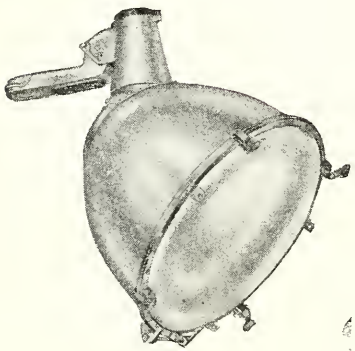
Portable Or Stationary

GENERAL SPECIFICATIONS

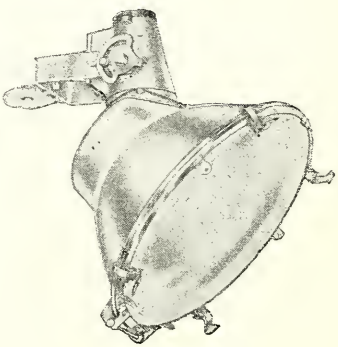
(Depending upon type and capacity)

Capacities	75–2000 Watt PS 250–1500 Watt G
Efficiency	34% to 78%
Beam C. P.	6000 to 600,000
Beam	10 degrees to 120 degrees
Diameter	7½" to 20" symmetrical reflectors
Reflectors	Matte or Specular finish
Mounting	Cross Arm—Pipe Clamp—Pipe Slip Fitter
Adjustment	Universal
Lenses	Plain or spread type glass, heat resisting or heat and shock resisting
Parts	Rust resistant

Illumination Data from tests by Electrical Testing Laboratories and by F. W. Maxstadt, California Institute of Technology



No. 952-CAL
69.5% Efficiency
750-1500 Watts



No. 1052-YCAL
62% Efficiency
750-1500 Watts

Used for Commercial, Recreational and Industrial Liteing

Engineering Collaboration and Catalog available upon request

*Process patented by Aluminum Company of America

S & M Lamp Co.

119 W. 36th Place — Los Angeles 54, Calif.

AIA File 31F23 & 24

"Red Cap" Aluminum Flood-Lites

Alzak* Processed

PERTINENT CONSTRUCTION FEATURES

Weatherproof type Flood-Lites have nonventilated cast aluminum alloy housings, trunnions and bases.

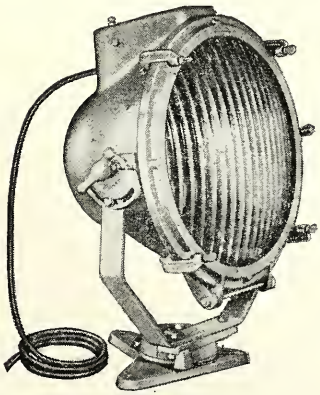
Semi-weatherproof and open type Flood-Lite mounting brackets are interchangeable.

Reflectors of wide, medium or narrow beam spread, are interchangeable for any one series group of Flood-Lites.

All Flood-Lites are suitable for suspension mounting by using "Thompson" hanger and requisite accessories.

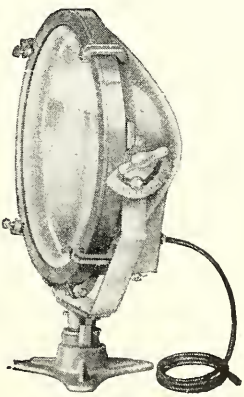
All open and semi-weatherproof types of 500 watt and larger capacity, as well as all weatherproof types of Flood-Lites, have angular adjustment quadrants and stops.

Are Underwriters Laboratory Approved
(or Approval Applied for)



No. 2020-ST
38% Efficiency
750-1500 Watts

Used for Industrial Liteing



No. 1801-ST
78% Efficiency
500-1000 Watts

* Process patented by Aluminum Company of America

THE SAFETY CAR HEATING AND LIGHTING COMPANY INC

NEW YORK • CHICAGO • PHILADELPHIA • ST. LOUIS • SAN FRANCISCO • NEW HAVEN • MONTREAL

Complete Car Lighting Systems

from Design to Installation

Experienced Engineering and

Manufacturing Facilities,

with a Record of 60 Years

Service to America's Railroads

SAFETY COMPANY PRODUCTS INCLUDE:

COMPLETE AIR CONDITIONING EQUIPMENT
GENEMOTORS
GENERATORS
MOTOR ALTERNATORS
REGULATORS
LIGHTING FIXTURES
SWITCHBOARDS
FANS
PARCEL RACKS
GENERATOR DRIVES

FOR RAILROAD CARS

M-128

SALES REPRESENTATIVES IN 19 PRINCIPAL CITIES

Sandee Manufacturing Company

5050 FOSTER AVENUE • CHICAGO 30, ILLINOIS

EXTRUDED PLASTICS AND SPECIAL TOOLS

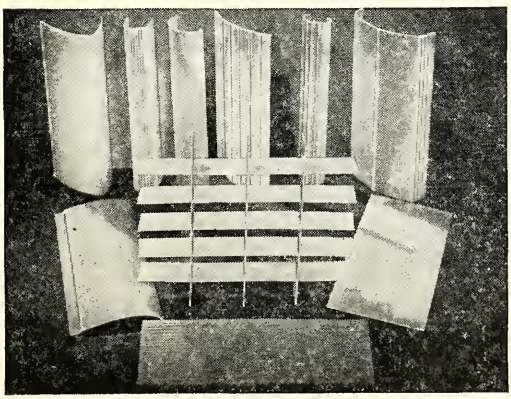
SANDEE EXTRUDED PLASTIC SIDE SHIELDS AND LOUVRES FOR FLUORESCENT FIXTURES

Custom sections extruded from translucent Polystyrene contribute the following advantages to Fluorescent Fixtures:

1. Controlled light transmission and diffusion
2. Excellent dimensional stability
3. Excellent rigidity
4. Light weight—Specific Gravity 1.06
5. Ease of cleaning
6. Greatly increased aesthetic design possibilities.
7. Increased over-all lighting efficiency.

Outstanding Properties of Sandee Polystyrene

1. *Specific Gravity —1.06*
2. *Tensile Strength —5500 to 7000 P.S.I.*
3. *Impact—0.5 ft. lbs (notched)*
4. *Heat distortion —175° F*
5. *Rigidity —Excellent*
6. *Dimensional Stability —Excellent*
7. *Water Absorption —Nil*
8. *Burning Rate —Slow*
9. *Electrical properties —Excellent*
10. *Odor —None*
11. *Color —Unlimited*
12. *Finish —High Gloss if Desired*



Sandee offers the newest, most modern, and one of the largest facilities for producing extruded plastic sections in all sizes and shapes. Special attention is suggested to the new "Egg Basket" Louvres of translucent Polystyrene, illustrated here.

L. J. SEGIL CO.

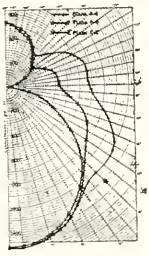
2500 W. NORTH AVE., CHICAGO 47

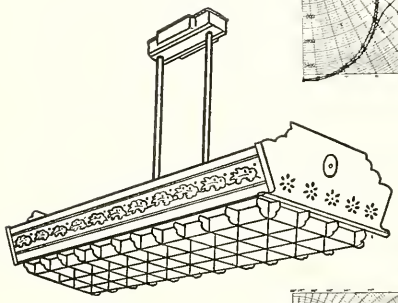
Manufacturers of

FLUOR DE LE FLUORESCENT LIGHTING

A comprehensive line of commercial and industrial lighting developed with a view to good, sturdy, simple construction. Commercial features are semi-circular body with girder construction top which provide high output reflection, ease of cleaning and hanging. Available in many types, glass, glass and louvre enclosures, as well as unshielded, 2, 3, 4 and 5 lamp styles for both 20 and 40 watt lamps.

THE LIGHT DIRECTOR FULS

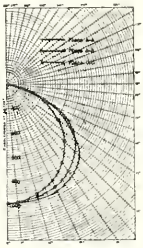


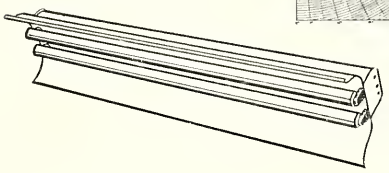


A good popular combination of side diffusing glass and efficient bottom louver. This affords adequate illumination with minimum glare and light loss. Glass panels and louver easily removed for cleaning. Body and ends finished with baked Durowhite enamel. Equipped with polished chrome stems.

Length 49″ Width 17″ Height 7″
Same style available with diffusing glass bottom ✱FHGS and FUS.

INDUSTRIAL REFLECTOR





Fully designed to give efficient light for factory work and areas where light must be concentrated on the working plane. Provision for varying hanging angle at each end of housing.

Industrial types available in 3 reflector widths 9¼″, 12″ or 13½″, 1, 2, 3 and 4 lamp styles in baked Durowhite or porcelain enamel with gray exterior. 20 and 40 watt sizes.

Candlepower distribution charts made by Electrical Testing Laboratories, New York, N. Y.

All styles both commercial and industrial are gangable end to end without elaborate accessories and may be mounted on ceiling or suspended.

For detailed information write for complete catalog.

M-130

SILVRAY LIGHTING, INC.

R.K.O. Building, Radio City
New York 20, New York

INTEGRATED LIGHT CONTROL

(Silvray Processed Lamp)



Efficient light control at the source is the basic concept of *Integrated Light Control* with silver processed lamps. Redirection of bare lamp emission is obtainable in nearly all zones by application of a silver mirrored surface directly on any portion of the glass bulb of nearly all commercially available lamps.

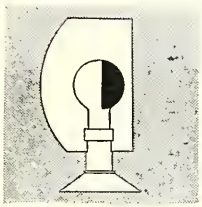
This reflecting surface is guaranteed not to dull, tarnish or peel during the life of the lamp. Maintained performance is assured because each lamp replacement provides a new reflector system.

The integration of light source and reflector as a component offers potentialities in space saving at efficiencies of 90% to 95% in terms of bare lamp emission.

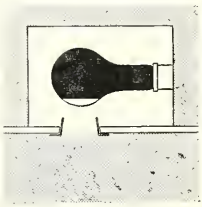
Numerous sizes, wattages and voltages of light sources produced by lamp manufacturers carefully engineered and processed by Silvray to provide a variety of light distributions offer effective, efficient and economic light control for nearly all fields of lighting application.

Consult your local utility or lamp company lighting engineer or contact Silvray direct for assistance in your application problems.

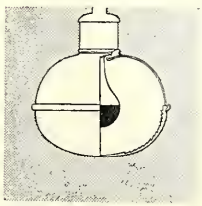
APPLICATION IDEAS
WITH INTEGRATED LIGHT CONTROL



In floodlighting partial silvering of the lamp provides the potentialities of better definition of beam pattern, higher beam efficiency, reduced spillage and minimized glare from the source. Applicable to "G" and "PS" bulb shapes.



Downlights may be installed in places where space limitations preclude the use of more elaborate systems. "Bullseye" openings in processed miniature or standard lamps provide a wide selectivity. This is the basic concept of the highly effective "gun-sight" lamps.

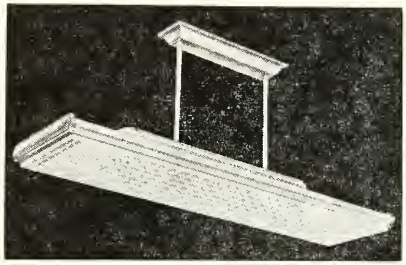


Silvray Processed Lamps offer a solution to certain excessive glare factors in street and highway lighting. Intrinsic brightness of the light source is a basic consideration in any approach to the elimination of annoying glare from fixed lighting on public ways. Silvray Processed Street Lighting lamps in properly designed luminaires can provide completely adequate shielding of the source with a minimum loss in efficiency.



Simple, effective and economical high-bay lighting installations may be obtained with shoulder or neck silvered lamps. The illustration shows the possibilities of simplicity in fixture design wherein a metal ring protects the lamp from mechanical damage and also serves as a glare shield for normal viewing angles. Initial cost and maintenance expense can be reduced to a minimum with a continuance of high efficiency.

SILVRAY LIGHTING, INC.



NO. 604 F. S.

This 4-lamp Silvray unit introduced egg-crate shielding and shallow body construction; patented "diamond reflector" system assures high efficiency and minimum maintenance. "Holdsure" latch permits easy lowering of shield for cleaning. Sturdy steel, die-formed construction. Finished in white polymerin. Connecting strap adapts for end-to-end mounting. Same design also available in 2-lamp construction.

Light Output (in terms of bare lamp)*

0°	90°	52.0%
90°	180°	34.0%

With louver

0°	90°	42.0%
90°	180°	35.0%

NO. 80 — NO. 120 — NO. 160

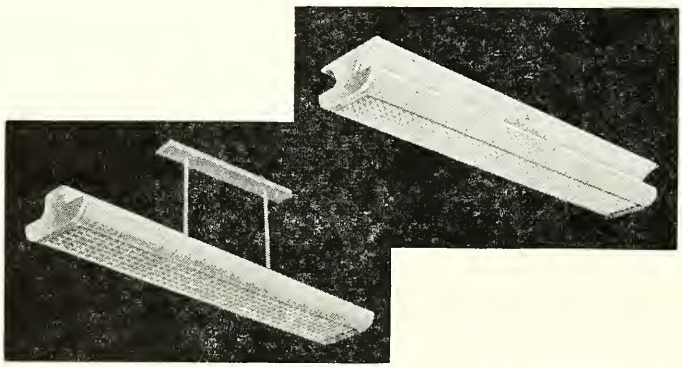
Among the new additions to the Silvrescent line is this new, compact, shallow cross-section luminaire only $5\frac{3}{4}''$ deep and $10\frac{1}{2}''$ wide. Meeting a demand for installation continuity with variation in illumination levels, the same housing is available in the No. 80 (2–40 w.), the No. 120 (3–40 w.) and the No. 160 (4–40 w.). Die-formed steel construction throughout. Exclusive "Slot-Louvring" of side panels reduces brightness. The Silvray concept of "Brightness Modification" is also available in plastic inserts of several densities. Egg-crate louvers (1" square openings) provide 45° shielding of the bottom section.

Entire shield hinged for easy maintenance.

Light Output (in terms of bare lamp)*

0°	60°	32.0%
0°	90°	44.5%
90°	180°	20.0%

For individual or continuous mounting.



NO. 80-S — NO. 120-S — NO. 160-S

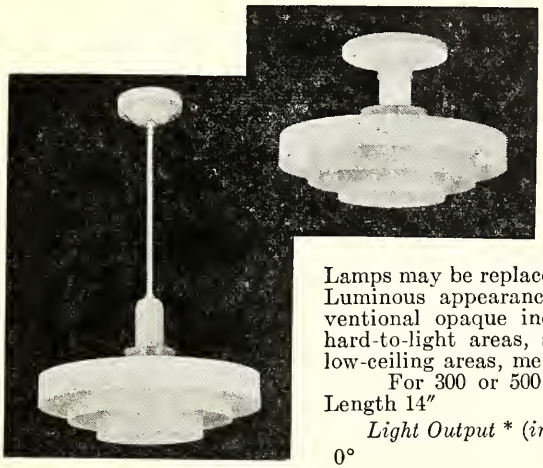
Suspension-type units with same design characteristics as No. 80 and No. 160. Features a shallow canopy and a 48" ballast housing. In both the ceiling mounted and suspension types, the slot-louvers and center shield are one-piece units which are held by two hinges when lowered for cleaning or replacement of lamps, etc. For individual suspension the No. 80-S (2–40 w.), the No. 120-S (3–40 w.), and No. 160-S (4–40 w.) are equipped with shallow canopy and double stem support. For end-to-end use, the new Silvray "Chanopy", combining a continuous canopy and wiring channel is available.

Light Output (in terms of bare lamp)*

0°	60°	28.0%
0°	90°	36.0%
90°	180°	34.0%

* All illumination data from tests by Electrical Testing Laboratories Inc.

SILVRAY LIGHTING, INC.



NO. 1500

Sturdy steel construction. Three concentric rings designed to provide complete shielding of the Silvered Bowl lamp. For totally indirect illumination. Vertical plane of rings prevents collection of dirt, insects, etc. Design minimizes interception of reflected light from ceiling. Lamps may be replaced from floor with lamp changer. Luminous appearance eliminates objection to conventional opaque indirect fixtures. A solution for hard-to-light areas, such as natural coffer ceilings, low-ceiling areas, mezzanines.

For 300 or 500 watt Silver Bowl Lamps

Length 14″ Diameter 19″

*Light Output * (in terms of unprocessed lamp)*

0°	60°	3%
0°	90°	5%
90°	180°	82.5%

Adaptable for the Semi-Silvered Bowl Lamp for high-lighting displays.
Also available in other sizes ranging from 75 watt to 500 watt, with 2–3–4 ring construction.

NO. 1500-S

This is the standard ⁂1500 body but furnished with a stem suspension which permits its use in applications that are not suited to close-to-ceiling fixtures. The ⁂1500-S is particularly well adapted for use with the recently announced Semi-Silvered Bowl lamp. The wide cone of direct downward light from the semi-silvered bowl lamp is particularly valuable in building up the illumination on merchandise on store counters, tables and cases, and in adding life and sparkle through reflections of the bright bowl from some types of merchandise. Because of their brightness, the Semi-Silvered Bowl lamps, in direct contrast to the Silvered Bowl Lamps, are in no case recommended for use in school rooms or in offices.

Also available in 4-ring construction for 750 w. and 1000 w. lamps.

NO. 207/PL

A plastic bowl unit for use with 300–500 watt Silvered Bowl lamps. The shallow bowl member is lighted to a pleasing degree with a maximum bowl brightness of less than 1.5 Cp. per square inch.* Lamp neck is fully shielded by aluminum truncated cone which rests on bowl-supports. Three plated concentric rings separate the bowl from the lamp. Reclamping effected from below without need to remove bowl or handle fixture.

For use with 750 or 1000 watt lamps, a plastic bowl unit of similar design (Catalog ⁂210/PL) should be specified.



**Light Output (in terms of unprocessed lamp)*

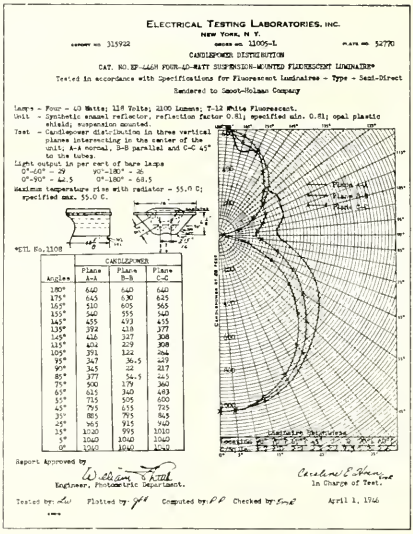
0°	60°	2.0%
0°	90°	3.5%
90°	180°	86.0%

SMOOT-HOLMAN COMPANY
Inglewood, California

Sales Agents in Principle Cities
BRANCH AND WAREHOUSE: 460 SEVENTH ST. SAN FRANCISCO 3

PLASCOLIER

The adaptation of plastics as a diffusing medium results in reduction both of weight and hazards of breakage. The technique used in the forming of the plastic, together with the method of supporting the diffuser, reduces framing to a minimum and eliminates barriers to the free flow of light.



ELECTRICAL TESTING LABORATORIES, INC.
NEW YORK, N. Y.

CANDLEPOWER DISTRIBUTION

CAT. NO. EF-4440 FOUR-40-WATT SUSPENSION-MOUNTED FLUORESCENT LUMINAIRE*
Tested in accordance with Specifications for Fluorescent Luminaires - Type - Semi-Direct
Rendered to Smoot-Holman Company

Lamps - Four - 40 Watts; 118 Volts; 2100 Lumens; T-12 White Fluorescent.
Unit - Synthetic enamel reflector, reflection factor 0.81; specified min. 0.81; opal plastic shield; suspension mounted.
Test - Candlepower distribution in three vertical planes intersecting in the center of the unit; A-A normal, B-B parallel and C-C 45° to the tubes.
Light output in per cent of bare lamps
0°-60° - 29 90°-180° - 36
0°-90° - 42.5 0°-180° - 68.5
Maximum temperature rise with radiator - 55.0 C; specified max. 55.0 C.

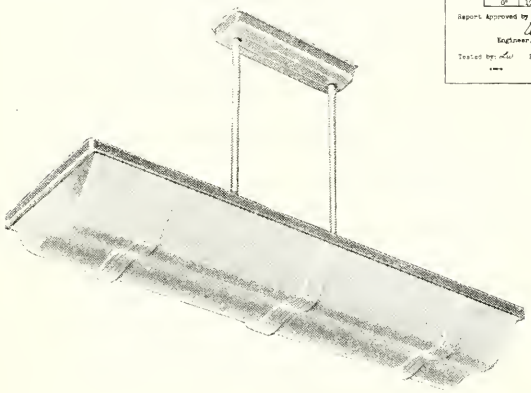
*ETL No. 1108

Angles	CANDLEPOWER Plane A-A	Plane B-B	Plane C-C
180°	640	640	640
175°	645	630	625
165°	610	605	565
155°	560	555	540
145°	455	493	455
135°	392	418	377
125°	328	327	308
115°	404	229	308
105°	391	122	294
95°	347	36.5	249
90°	345	22	217
85°	377	54.5	445
75°	500	179	360
65°	625	340	493
55°	715	505	600
45°	795	655	725
35°	885	795	845
25°	965	935	940
15°	1020	995	1010
5°	1040	1040	1040
0°	1040	1040	1040

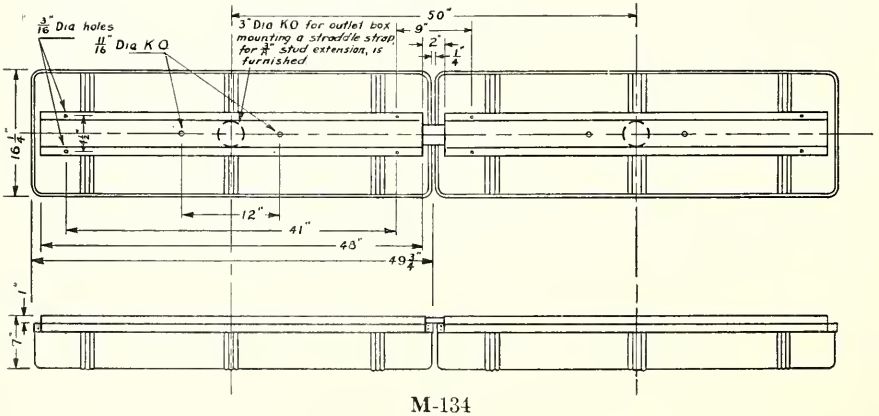
Report Approved by
William J. Kroll
Engineer, Photometric Department.

Cleveland E. Stephens
In Charge of Test.

Tested by: LH Plotted by: GH Computed by: RP Checked by: CES April 1, 1946

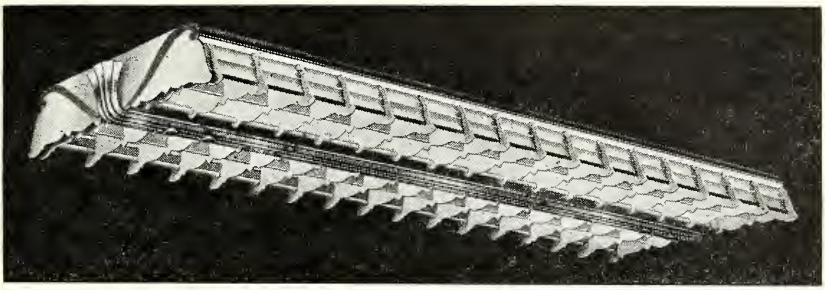


Certified FLEUR-O-LIER LUMINAIRE
CERTIFIED ETL
SPECIFICATIONS OF THE FLEUR-O-LIER MANUFACTURERS
Electrical Testing Laboratories, Inc.

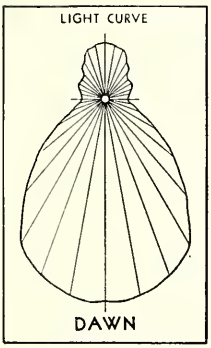


SMITHCRAFT LIGHTING DIVISION

Chelsea 50, Mass.

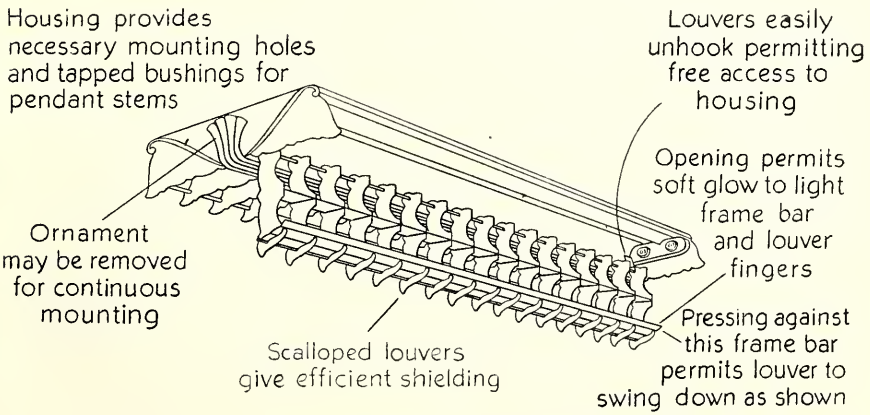


Smithcraft Dawn



E.T.L. data available on request

The Smithcraft DAWN. Scalloped louvers provide efficient lamp shielding. "Louver fingers" positioned on outside of frame permit a soft glow to spill on fixture exterior. Parabolic side reflectors, part of the rigid die-formed steel housing, are finished in White Supercoat Baked Enamel. V type reflectors give 75% down lighting. Louvers are hinged in two sections and may be swung open by pressing against outside of frame. This brings lamps, starters and housings in full view for easy servicing. Louvers can be handily taken down for cleaning. Ballasts, wiring etc. are built within, so that fixture may be flush-mounted to ceiling without intervening space. It can be pendant mounted, using Smithcraft Non-Turn Lock Canopy Set. Removal of one screw on end cap reveals a wireway for continuous mounting. Listed by Underwriter's Laboratories.

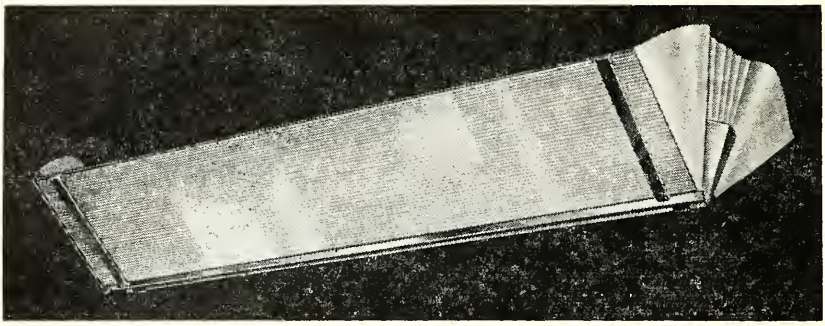


SPECIFICATIONS

No. of Lamps	Dimensions	Louver	Finish	Cat. No.
4 40-watt	17¾ wide x 49½ long x 3⅛″ deep	Hinged in two sections lengthwise and removable	Supercoat white Baked Enamel & aluminum	A-4

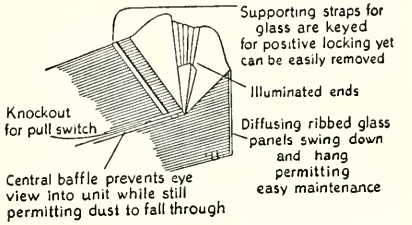
A complete line of commercial and industrial units including troffers.

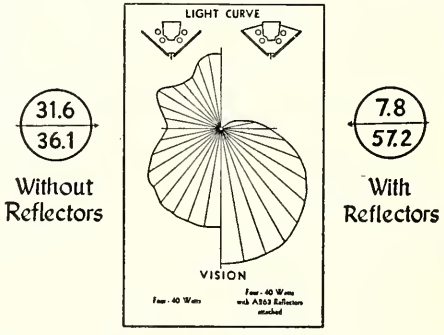
SMITHCRAFT LIGHTING DIVISION



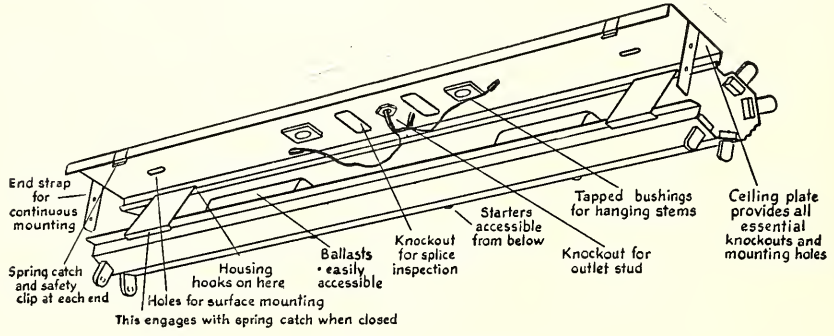
Smithcraft Vision

The Smithcraft VISION. V type fluorescent with ribbed diffusing-glass panels which are frameless for easy cleaning. The decorative end caps are illuminated by a soft spill of light and are finished with a combination of white and aluminum. Glass panels secured or released by spring catches. Continuous opening at bottom lets dirt and insects fall through. May be quickly and easily mounted flush using ceiling plate as shown in diagram or hung pendant or continuous. Housing of rigid die-formed steel construction, contains ballasts, wiring etc., and are handily accessible for maintenance. Listed by Underwriters' Laboratories.





E.T.L. data available on request

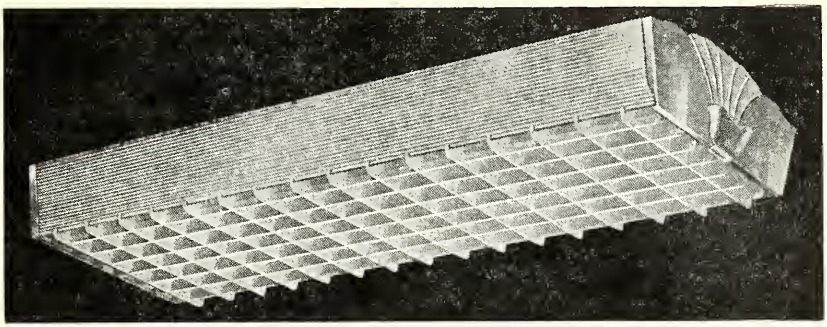


SPECIFICATIONS

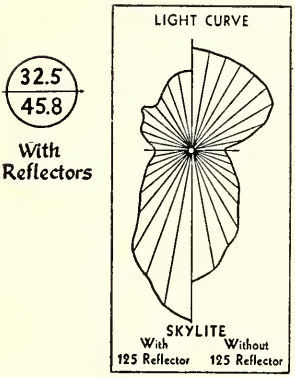
No. of Lamps	Dimensions	Glass	Finish	Cat. No.
V2 2—40 w. V4 4—40 w.	14″ wide x 48¼″ long x 8″ deep	Frosted Prismatic Panels	Supercoat white Baked Enamel & aluminum	V-4

A complete line of commercial and industrial units including troffers.

SMITHCRAFT LIGHTING DIVISION

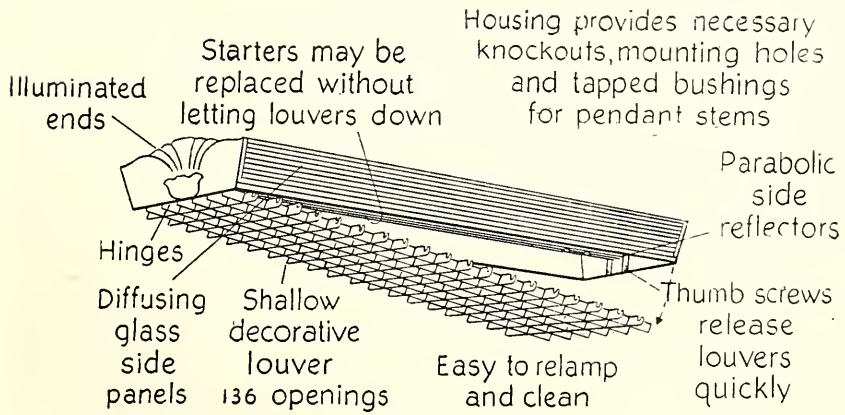


Smithcraft Skylite



E.T.L. data available on request

The Smithcraft SKYLITE. Ribbed diffusing-glass side panels. Opening on end cap permits soft spill of light. Shallow hinged louver at bottom swings down for maintenance. Housing channel has built-in parabolic reflectors providing greater down lighting. The louver with 136 openings is designed to give low surface-brightness. Additional strip reflectors can be attached to give down-lighting component of 65% with 35% up-lighting. Housing of rigid die-formed steel construction, and ballasts, wiring etc. are built within so that fixture may be mounted flush to ceiling without intervening space. May also be pendant or continuous mounted. Listed by Underwriter's Laboratories.

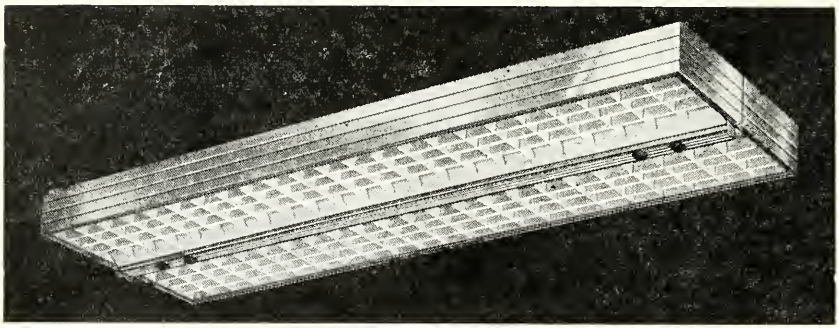


SPECIFICATIONS

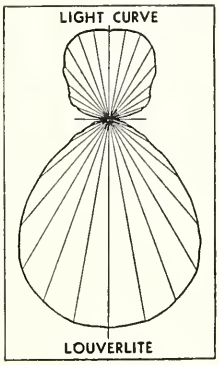
No. of Lamps	Dimensions	Louver	Finish	Cat. No.
4 40-watt	17″ wide x 49″ long x 6½″ deep	Hinged steel 1⅛″ deep, 136 openings	Supercoat white Baked Enamel & aluminum	YE-4

A complete line of commercial and industrial units including troffers.

SMITHCRAFT LIGHTING DIVISION



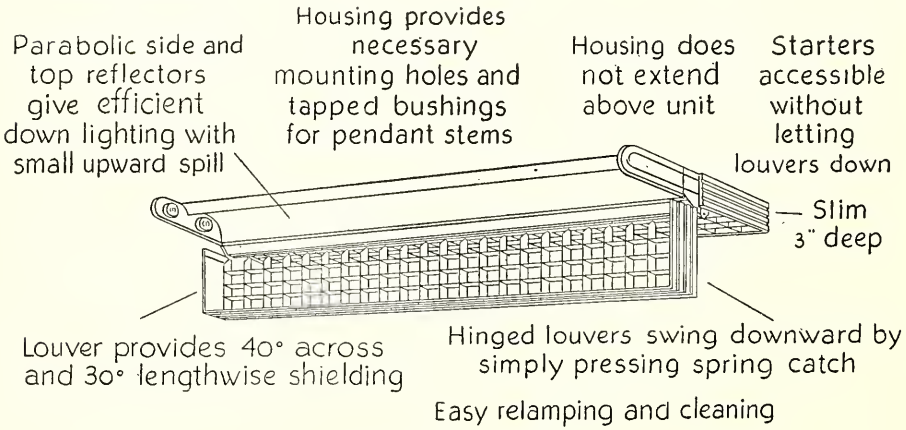
Smithcraft Louverlite



E.T.L. data
available on request

28.4
47.1

The Smithcraft LOUVERLITE. Shallow louvers with 40° across and 30° lengthwise shielding provides smoothly diffused sheet of light. Parabolic side reflectors and V reflectors between lamps, direct most light downward. Louvers are hinged in two sections and easily released by springs, bringing lamps and housing into full view. Louvers are also completely removable. Housing of rigid die-formed steel construction, and ballasts, wiring etc. are built within so that fixture may be mounted flush to ceiling without intervening space. May also be hung pendant or continuous. Listed by Underwriter's Laboratories.

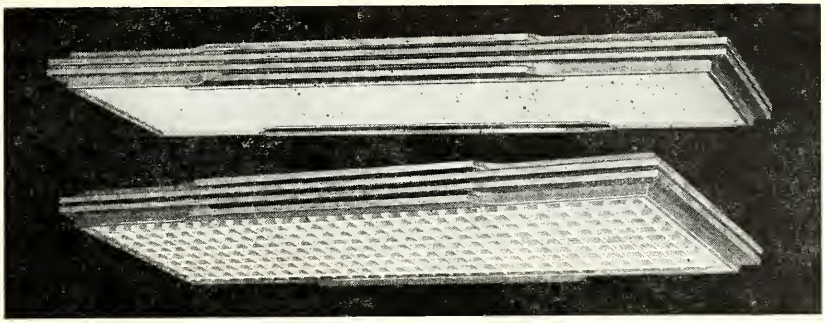


SPECIFICATIONS

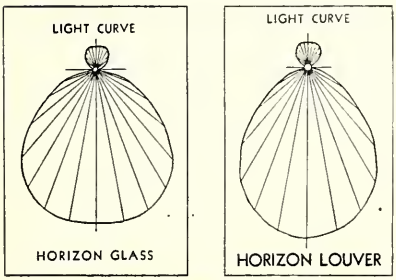
No. of Lamps		Dimensions	Louver	Finish	Cat. No.
4	40-watt	16″ wide x 51″ long x 2 7/8″ deep (at frame)	Hinged steel two sections	Supercoat white Baked Enamel & aluminum	OO-4

A complete line of commercial and industrial units including troffers.

SMITHCRAFT LIGHTING DIVISION

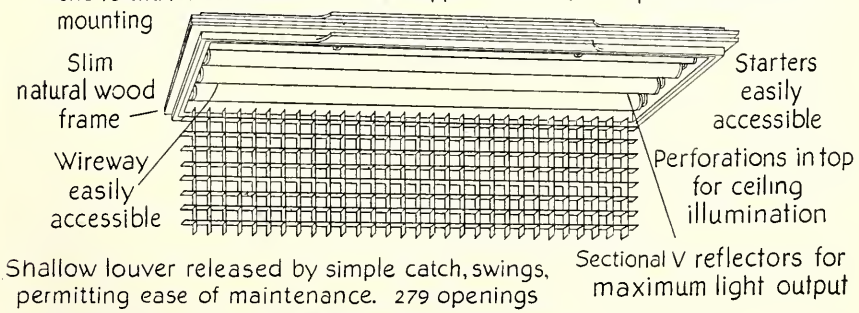


Smithcraft Horizon



E.T.L. data available on request

The Smithcraft HORIZON. Natural wood frame over sturdy die-formed housing containing ballasts, wiring, etc. Unit can be mounted flush without intervening space, or pendant mounted. Depth of fixture is only $2\frac{3}{4}$ inches. Top provides wiring channel to house wire leads, also knockouts to connect to outlet box. Closed top is provided for complete down-lighting. Open top with perforations gives 15% spill on ceiling. V reflectors over lamps for maximum light output. May be had with hinged louver or with sandblasted glass panel with clear line decoration. Listed by Underwriters' Laboratories.



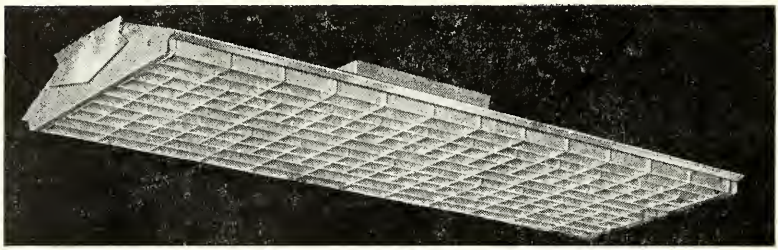
May be had in glass or louvered

SPECIFICATIONS

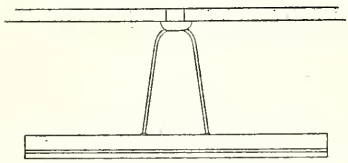
No. of Lamps	Dimensions	Louver or Glass	Finish	Cat. No.
4 40-watt	$17\frac{1}{2}$″ wide x $52\frac{1}{4}$″ long x $2\frac{3}{4}$″ deep	Steel eggcrate or glass sand blasted glass panel	Wood natural lacquered; steel supercoat white Baked Enamel	HG-4 (glass) HE-4 (louver)

A complete line of commercial and industrial units including troffers.

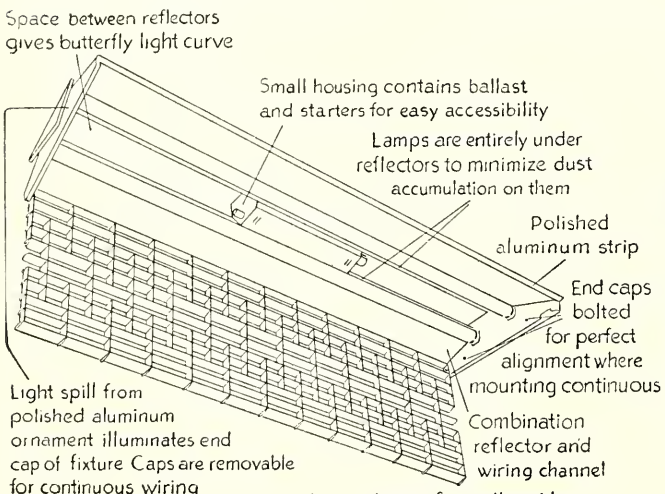
SMITHCRAFT LIGHTING DIVISION

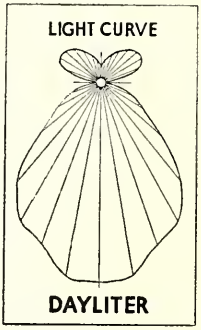


Smithcraft Dayliter



The Smithcraft DAYLITER. Shallow unit with louvers designed for 40° crosswise and 30° lengthwise shielding. Unique twin-type reflectors eliminate usual housing and emit butterfly shape light curve upward to illuminate ceiling. Lamps are under reflectors to minimize dust accumulation on them. Ballast and wiring channels easily accessible for continuous wiring. Louvers are hinged from both sides. Finished in White Supercoat Baked Enamel and bright aluminum trim. Individual Fixture or Continuous runs may be quickly and easily mounted flush to ceiling or as pendant. Listed by Underwriters' Laboratories.





E.T.L. data available on request

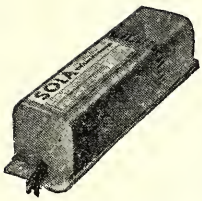
SPECIFICATIONS

No. of Lamps	Dimensions	Louver	Finish	Cat. No.
2 40-watt	15½" wide x 48" long x 3¾" deep	Hinged in one section lengthwise	Supercoat white Baked Enamel & aluminum	D-2

A complete line of commercial and industrial units including troffers.

SOLA ELECTRIC COMPANY

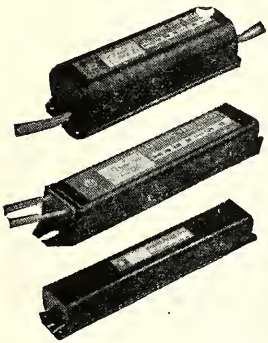
4633 West 16th Street, Chicago 50, Illinois



THINLINE TRANSFORMERS

Single and two lamp transformers designed specifically for the proper operation of 96T8 long, thin hot cathode fluorescent lamps. Gives instant starting and incorporates the SOLA Constant Voltage Principle for constant light output. For 29 Watt lamps (approx. 100 MA), 750 V. Listed by Underwriters' Laboratories, Inc.

Write for Bulletin 40FL-110

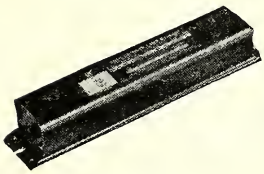


FLUORESCENT BALLASTS

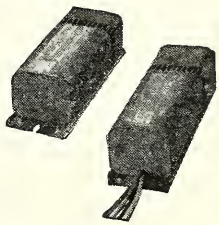
Available for operation of one 40 Watt (T-12), two 40 Watt (T-12) or two 100 Watt (T-17) fluorescent lamps. Constructed and designed for high operating efficiency, long lamp life, and silent operation. Listed by Underwriters' Laboratories, Inc.

Write for Bulletin 40FL-108

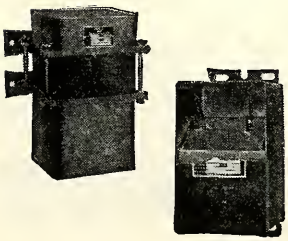
COLD CATHODE TRANSFORMERS



Designed for operation of 93 inch low pressure cold cathode lamps. Available in single and two lamp sizes. SOLA Constant Voltage Principle incorporated to give constant light output regardless of line voltage variations. Underwriters' listed.



Write for Bulletin 40CC-107-104



DOUBLE WOUND TRANSFORMERS

For lighting and general power applications, these heavy duty, double wound transformers insure permanent isolation of input and output circuits. Built-in outlet compartments with knock-outs for either rigid or flexible conduit. Compound sealed for moisture proofing. Available in capacities ranging from 50 VA to 10,000 VA.

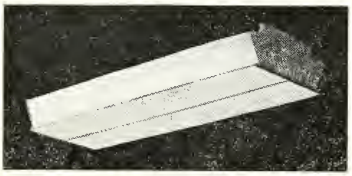
Write for Bulletin 40DW-113

SOLAR LIGHT MANUFACTURING CO.

1357 S. Jefferson Street, Chicago 7, Ill.

Over Forty Years of Lighting Service

FLUORESCENT

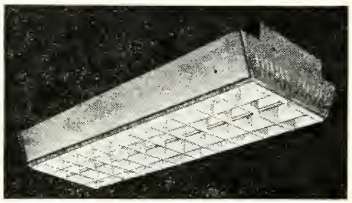


Research Luminaire 5000 Series

Catalog	*Lamps*	*Length*	*Width*	*Height*	*Weight*
5248	2/40W	48¾″	15″	7¼″	40 lbs
5424	4/20W	24¾″	19″	7¼″	28 lbs
5448	4/40W	48¾″	19″	7¼″	60 lbs
5648	6/40W	48¾″	23⅝″	7¼″	70 lbs

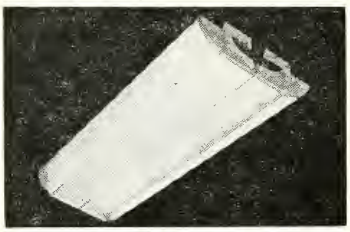
Developed from Original U.R.C. design Luminaires of low surface brightness. Side panels are white ceramic ribbed glass, light transmission approximately 30%. Bottom panels are "Skytex" a clear prismatic ribbed glass of high light transmission, low surface brightness. An efficient reflector, finished in baked white enamel improves the downlight component and reduces the ceiling brightness above the fixture. Efficiency of the #5448 is 69%.

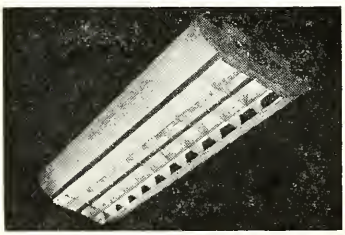
Louvered Luminaire 8000 Series

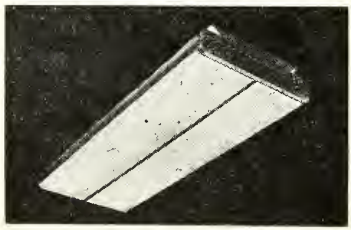


Catalog	*Lamps*	*Length*	*Width*	*Height*	*Weight*
8248	2/40W	48¾″	15″	7⅞″	40 lbs
8424	4/20W	24¾″	19″	7⅞″	28 lbs
8448	4/40W	48¾″	19″	7⅞″	60 lbs
8648	6/40W	48¾″	23⅝″	7⅞″	70 lbs

Basic construction is the same as the Research unit except for steel louvers finished in baked blue white enamel. Shielding is 35° crosswise and 30° lengthwise. Louvers swing down for relamping. Side panels are of white ribbed "Alba-lite" glass homogeneous in texture and permanent in color. Light transmission is approximately 65%. The reflector is a feature of this fixture. Efficiency of the #8448 is 61.1%.







Curved Panel Glass Bottom Luminaire 10000 Series

Catalog	*Lamps*	*Length*	*Width*	*Height*	*Weight*
10248	2/40W	48¾″	14¼″	5½″	37 lbs
10448	4/40W	48¾″	18½″	5½″	60 lbs

Curved sides are of either Polystyrene or "Alba-lite" glass (as specified). Light transmission of Polystyrene is approximately 30% and of Alba-lite approximately 65%. Bottom glass is of clear skytex or Alba-lite (as specified). Reflector is a feature of this fixture. Efficiency of #10448 is 77%.

Curved Panel Louvered Bottom Luminaire 9000 Series

Catalog	*Lamps*	*Length*	*Width*	*Height*	*Weight*
9248	2/40W	48¾″	14¼″	6″	37 lbs
9448	4/40W	48¾″	18½″	6″	60 lbs

The curved sides are of either Polystyrene or "Alba-lite" glass (as specified). Light transmission of Polystyrene is approximately 30% and of Alba-lite approximately 65%. Louvers are same as for #8000 series units. Shielding, however, is 40° crosswise and 30° lengthwise. The reflector is a feature of this fixture as is its simple functional design. Efficiency of #9448 is 65%.

Solar Panel 12,000 Series

Catalog	*Lamps*	*Length*	*Width*	*Height*	*Weight*
12448	4/40W	49″	20″	5″	75 lbs
12648	6/40W	49″	20″	5″	80 lbs

The reflector sides of this fixture and the "Alba-lite" bottom panels with curved edges make it appear slim and thin. Light distribution is unusually broad and even. It will provide an abundance of general illumination. Slimline lamps may be used with these fixtures (when specified). Efficiency is 61%.

SOLAR LIGHT MANUFACTURING CO.

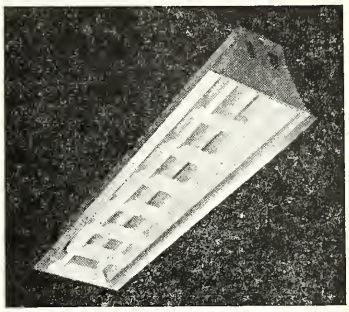
1357 S. Jefferson Street, Chicago 7, Ill.

Over Forty Years of Lighting Service

FLUORESCENT

Recessed Troffer Fixtures

Catalog	*Lamps*	*Length*	*Width*	*Height*	*Weight*
6148	1/40W	48″	12″	9⅜″	25 lbs
6248	2/40W	48″	12″	9⅜″	30 lbs
7248	2/40W	48″	12″	7″	45 lbs



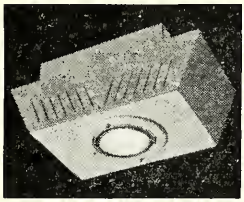
The #6148 and 6248 are deep troffers made of Alzak Aluminum. Louvering is of wide egg crate design and material is steel finished in blue white baked enamel. Shielding is 35° crosswise and 25° lengthwise. Efficiency of the 6148 is 65% and for the 6248 is 55.9%.

The #7248 is a shallow troffer made of steel with blue white baked enamel reflecting surfaces. Bottom panel is of "Albalite" glass, metal edged and piano-hinged to swing down for relamping.

Mounting straps to fit any type ceiling, finishing end flanges and louvers are to be specified separately.

INCANDESCENT

Gimbal Ring Type Fixtures For 150 Watt Par-38 Bulbs



#155



#156



#162

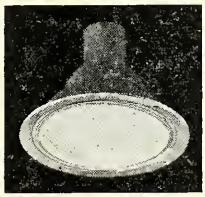


#163

Catalog	*Mounting*	*Canopy Diameter*	*Can Diameter*	*Overall Height*	*Shipping Weight*
155	Inline			7¼″	
156	Recessed	9½″	8″	6″	10 lbs
162	Surface	9½″	9½″	6″	10 lbs
163*	Recessed	7¼″	6″	8″	5 lbs

Gimbal rings permit 360° rotation and 0° to 30° deflection from vertical axis. Tapered Louvers and plaster rings are available and should be specified separately when wanted

*Fixed downlight (no gimbal ring) designed for R-40 Bulb.



#2916



#9840

Recessed Down Lights

Catalog	*Lamp*	*Maximum Diameter*	*Lens Diameter*	*Height*	*Weight*
2915	150/200W	12½″	8″	10½″	5 lbs
2916	300/500W	14¼″	11¼″	12¼″	8 lbs

Material is aluminum with specular Alzak reflector. Lens is prismatic Pyrex glass mottled back for diffusion. Hinged lens swings down for relamping. Use wherever downlight from ceiling is required. Efficiency of #2915 is 62% and for the #2916 it is 60%.

Suspended Enclosing Globe Fixture

Catalog	*Lamp*	*Diameter*	*Bowl Height*	*Weight*
9165	300/500W	18″	6″	20 lbs
9168	200W	15″	5½″	18 lbs
9840	300/500W	18″	11¼″	35 lbs

The 9165 and 9168 glass bowl is of white opal glass with removable bottom plate for relamping. The 9840 has a hinged Pyrex glass lens 11¼″ in diameter identical to that of the #2916 Recessed unit. Material is of Aluminum with Alzak reflector. Distribution is concentrating and suitable for store lighting.



#9165

Sperti inc.

Norwood Station, **Cincinnati, 12, Ohio.**

Sperti, Inc. is a company whose principal product is invisible, weightless and formless. Its effects are both useful and varied, however, ranging from erythemal (tanning), bactericidal, anti-rachitic, to color-corrected lighting. The reference is, of course, to the ultraviolet spectrum and its many functions.

Of principal interest to Illuminating Engineers is the use of the near-ultraviolet spectrum in combination with the incandescent to obtain high quality, color-corrected illumination together with the air sterilizing and hygienic properties of the germicidal ray. This lighting fixture is made in both direct and indirect ceiling-suspended fixtures, as well as an indirect type Torchere Floor Lamp. A combination of ultraviolet and fluorescent lighting in a single fixture is also planned.

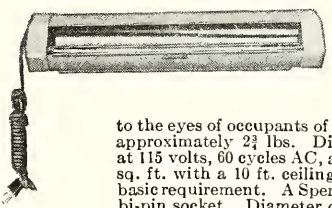
Other products of the company make use of the tanning and healthful properties of its various model Sunlamps. Still others are in the germicidal ultraviolet field including wall mounted sanitizers, seat sterilizers, glass sanitizers, units for meat cooler boxes, air-duct fixtures, and other special applications. Other divisions of the company make products not in the lighting field.

COLOR CORRECTED GERMICIDAL LIGHTING



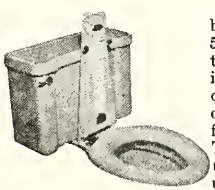
A combination of mercury arc and incandescent lighting in either direct or indirect fixture, designed for the purpose of obtaining color corrected lighting as well as simultaneous germicidal action of the associated ultraviolet lamps. Particularly suitable for schools, hospitals, restaurants, churches, window displays or where merchandise must be displayed to best advantage. Minimized stroboscopic effect. High power factor. The aluminum reflector 22 inches in diameter. Standard length is 43 inches. The two ultra-violet tubes (standard intermediate base) and one incandescent lamp (mogul base, 110 volt) are wired independently. Either or both ultraviolet and incandescent may be used. Operation is at 115 volts AC and only two wires are used for connection. Approximate weight 5 lbs. Two wattages are available in the incandescent lamp—300 or 500. Forty-five watts are expended in each of the ultraviolet lamps. No additional ballast is required. Installation is usually on 10 foot centers. In the 300 watt direct fixture, maximum downward illumination is about 520 candlepower at 10 feet; and maximum upward at about 35 degrees from the vertical is about 690 candlepower at 10 feet. In the 300 watt indirect fixture, there is essentially no direct illumination downward while the upward maximum is at 45 degrees from the vertical at about 820 candlepower. Measurements were made by E.T.L.

ULTRAVIOLET GERMICIDAL FIXTURE



A complete and practical ultraviolet radiation unit for destroying airborne organisms which cause colds and other infectious diseases. Approximately 80% of the ultraviolet radiation is at the bactericidal wavelength of 2537 A.U. The case is so designed as to radiate most effectively forward and upward, with little or no radiation on the wall in the immediate vicinity of the lamp. When the unit is mounted seven feet from the floor, there is no direct radiation to the eyes of occupants of the room. The case is aluminum, finished in lacquer and weighs approximately 2¾ lbs. Dimensions are 18⅜″ wide, 4⅝″ deep, and 2⅜″ high. Operation is at 115 volts, 60 cycles AC, about 19 watts total consumption. One unit is used for about 100 sq. ft. with a 10 ft. ceiling and two person occupancy. Specific conditions may alter this basic requirement. A Sperti 53QZ Lamp is used with wattage of fifteen and standard medium bi-pin socket. Diameter of the lamp is 1″, and length 18″. Lamp life is about 3000 hours continuous, 2500 intermittent. Total radiation at 2537 A.U. is about 3 watts, which produces a maximum intensity perpendicular to the lamp at 10 feet of about 3 milliwatts per square foot. Air-borne bacteria are killed as they pass thru the fixture by convection currents.

ULTRAVIOLET SEAT SANITIZER



This unit is designed to fasten to most commode bowls by means of the two bolts which secure the lid. Center-to-center distance of the mounting feet is 5⅝″ and installations may be made with ⅛″ variation from this mean. Radiation is directed essentially downward and to the sides so that the seat is irradiated in either the upward or downward position. In addition to bactericidal action of the ultraviolet radiation, organic odors are reduced or eliminated through oxidation by a small amount of ozone produced. Dimensions of the unit are as follows: Height—19″; Width—8¼″; Depth—front to back—2″; Weight—6¼ lbs. The unit operates on 115 V, 60 cycles AC; 19 watts total consumption. A moisture-proof acid-resistant seat-actuated switch turns the lamp off. The entire unit is moisture resistant. A Sperti 53QZ lamp is used; and lamp life is about 2500 hours. Also available for DC or 220v AC operations.

SPERTI, INC.

Norwood Station, Cincinnati, 12, Ohio

ULTRAVIOLET GERMICIDAL INSTALLATION



A flexible, multi-purpose unit with associated number of ultraviolet lamps ranging from one to eight. The lamps may be placed anywhere and wired to the reactive ballast shown in the metal case. Equipment of this kind is used in meat storage boxes, production processes in which baeterial contamination is a threat, packaging and bottling operations, and wherever control of airborne bacteria is a necessity.

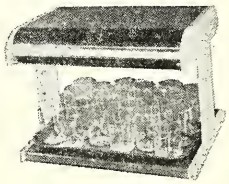
The lamps are designed according to patented principles to provide selective irradiation at desired wavelengths to the exclusion of others. When no more than 3 lamps are required, the 2605 ballast is used, and the installation is effective up to 100 square feet, depending upon the degree of bacterial reduetion required. When 3 to 8 lamps are required, the 2899 ballast is used, being effective up to about 300 sq. ft.

The units are tapped for operation at any line voltage from 105 to 130 AC only. Wattage consumed per lamp is about 50. The 2605 ballast unit dimensions are $13\frac{3}{4}$ long and $4\frac{3}{16}$" wide and $4\frac{1}{8}$" high. The larger 2899 ballast dimensions are $14\frac{3}{4}$ x 6 x $4\frac{3}{4}$—weight approximately 40 lbs. The lamps require a standard intermediate screw base, and are about 6" long.

ULTRAVIOLET GLASS SANITIZER

This unit is designed to supplement the standard disinfecting solutions used in cleansing glassware and other eating utensils in public restaurants. Its purpose is to provide sterile storage conditions for the articles until they are used by the customer. The unit is directly applieable, in many cases, to production processes as well.

Dimensions are: Height—11"; width—$19\frac{1}{2}$"; depth—front to back—$15\frac{3}{8}$". The unit is designed to accommodate standard size trays. A 15-watt Sperti 53QZ lamp is used, 18" in length, with suitable reflectors incorporated into the design of the unit. Operation is at standard line voltage of 115, at 60 cycles.



ULTRAVIOLET, COLOR-CORRECTED TORCHIERRE



A combination of mercury arc and incandescent lighting in an indirect lighting fixture of the torchierre variety. Color-corrected lighting is obtained, as well as simultaneous germicidal action of the associated ultraviolet lamps. Particularly suitable for business offices, waiting rooms, and other public gathering places. Minimized stroboscopic effect. High power factor. The two ultraviolet tubes (standard intermediate base) and one variable incandescent (3 way) lamp provides light which closely approximates daylight.

The ultraviolet sources may be operated independently of the incandescent lamp. The reflector is designed for maximum air flow and adequately shields ultraviolet tubes from direct observation. Maroon crackle finish with soft polished chrome trimming.

Diameter of the reflector is 16", of the base 14", height overall 68". Operation is at 115 volts, 60 cycles AC. Total power consumption is 100–200–300 watts in the incandescent lamp plus about 100 watts in the ultraviolet.

STEBER MANUFACTURING CO.

2700 Roosevelt Road, **Broadview (Maywood P.O.), Ill.**

A complete line of economical lighting units for Display, Flood, Utility, Farm and Industrial illumination requirements.

Data Sheet Information

The 3600 Series

Large efficient enclosed flood units with low maintenance factor. Available in Medium, Broad and Narrow beam for Airports, Shipyards, Docks, Outdoor Recreations, and for all purposes requiring flood illumination.

Economical for type and size.

Listed by the Underwriters' Laboratories, Inc.

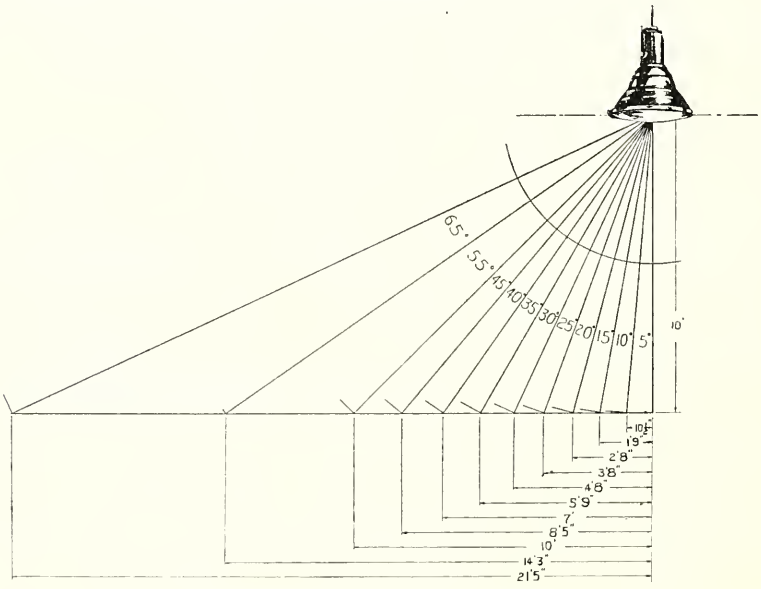
The 1600 Series

Medium size efficient enclosed flood units with low maintenance factor, for all purposes requiring a smaller unit than the 3600 series.

Economical for type and size.

Listed by the Underwriters' Laboratories, Inc.

Catalogs on full line may be had upon request.



Sample Spread for Lamp at 10 Ft. Height

x 2 for 20 ft. x 3 for 30 ft. x 10 for 100 ft.

Chart Information Data

The above chart, combined with the typical data sheets of Steber units, will give the foot candle intensity at various points, at various distances from the center of a Steber light source for the normal average mounting heights or distances of 10, 20, 30 and 100 feet.

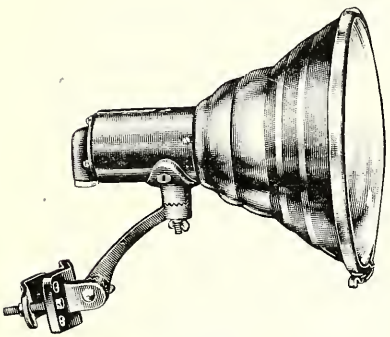
For convenience, the spread points from center are derived from angles intercepting the horizontal plane increasing by 5 degrees up to 45 degrees, and from then on, in 10 degree progressions.

Illumination data compiled at the Steber laboratory (Broadview, Illinois).

Data Calculated from a Point Source with Photo Cell Perpendicular to Normal.

STEBER MANUFACTURING CO.

2700 Roosevelt Road, **Broadview (Maywood P.O.), Ill.**

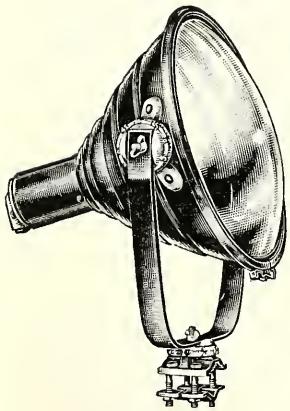


No. 1602
NARROW BEAM 500 WATT

Degrees	Spread in Feet from Center for 10 Ft. Height	Foot Candles of Lamp at 10 Ft. Height	Spread in Feet from Center for 20 Ft. Height	Foot Candles of Lamp at 20 Ft. Height	Spread in Feet from Center for 30 Ft. Height	Foot Candles of Lamp at 30 Ft. Height	Spread in Feet from Center for 100 Ft. Height	Foot Candles of Lamp at 100 Ft. Height
0	0—116.7		0—29		0—13		0—1	
5	10½″—112		1′8″—28		2′7″—12.4		8′9″—1	
10	1′9″—68		3′6″—17		5′3″—7.5		17′8″—.7	
15	2′5″—20		5′4″—5.5		8′—2.4		26′10″—2	
20	3′8″—15		7′3″—3.7		10′11″—1.6		36′10″—.1	
25	4′8″—11.5		9′4″—3		14′—1		46′8″—.1	
30	5′9″—9		11′6″—2		17′4″—1		57′9″—.1	
35	7′—8		14′—2		21′—.8		70′—.1	
40	8′5″—6		16′9″—1.5		25′2″—.66			
45	10′—5.7		20′—1.4					
55	14′3″—2		28′6″—.5					

No. 3601
BROAD BEAM
1500 WATT

Degrees	Spread in Feet from Center for 10 Ft. Height	Foot Candles of Lamp at 10 Ft. Height	Spread in Feet from Center for 20 Ft. Height	Foot Candles of Lamp at 20 Ft. Height	Spread in Feet from Center for 30 Ft. Height	Foot Candles of Lamp at 30 Ft. Height	Spread in Feet from Center for 100 Ft. Height	Foot Candles of Lamp at 100 Ft. Height
0	0—392		0—98		0—43.5		0—4	
5	10½″—353		1′8″—88		2′7″—39		8′9″—3.5	
10	1′9″—200		3′6″—50		5′3″—22		17′8″—2	
15	2′8″—163		5′4″—40.7		8′—18		26′10″—1.6	
20	3′8″—113		7′3″—28		10′11″—12.5		36′5″—1	
25	4′8″—67		9′4″—16.7		14′—7.4		46′8″—.7	
30	5′9″—41.6		11′6″—10.4		17′4″—4.6		57′9″—.4	
35	7′—27.7		14′—7		21′—3		70′—.3	
40	8′5″—21		16′9″—5		25′2″—2.3		84′2″—2	
45	10′—17		20′—4		30′—2			
55	14′3″—8		28′6″—2		42′10″—.8			



No. 3602
NARROW BEAM
1000 WATT

Degrees	Spread in Feet from center for 10 Ft. Height	Foot Candles of Lamp at 10 Ft. Height	Spread in Feet from Center for 20 Ft. Height	Foot Candles of Lamp at 20 Ft. Height	Spread in Feet from Center for 30 Ft. Height	Foot Candles of Lamp at 30 Ft. Height	Spread in Feet from Center for 100 Ft. Height	Foot Candles of Lamp at 100 Ft. Height
0	0—416		0—104		0—46		0—4	
5	10½″—225		1′8″—56		2′7″—25		8′9″—2	
10	1′9″—77		3′6″—19		5′3″—8.5		17′8″—.7	
15	2′8″—53		5′4″—13		8′—6		26′10″—.5	
20	3′8″—59		7′3″—14.7		10′11″—6.5		36′10″—.6	
25	4′8″—29		9′4″—7		14′—3		36′5″—.3	
30	5′9″—20		11′6″—5		17′4″—2		46′8″—.2	
35	7′—16		14′—4		21′—1.7		57′9″—.16	
40	8′5″—16		16′9″—4		25′2″—1.7		70′—.16	
45	10′—12.7		20′—3		30′—1.4		84′2″—.1	
55	14′3″—4.6		28′6″—1		42′10″—.5			

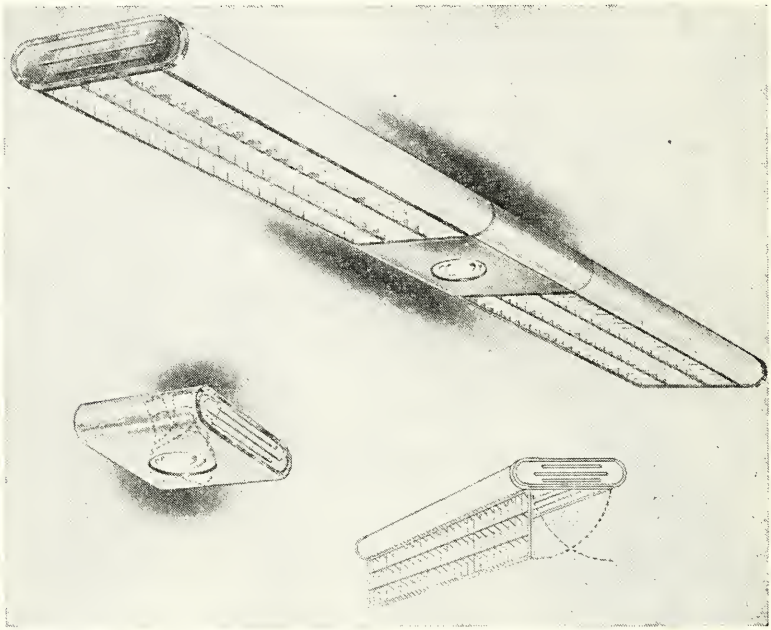
SUNBEAM LIGHTING COMPANY

777 E. 14th Place, Los Angeles 21, Cal.

Designers and Manufacturers of Fluorescent Lighting Fixtures

The Sunbeam Lighting Company manufactures a complete line of glass panel, strip, window display, industrial, recess, fully enclosed—with curved glass lenses or hinged louvre bottoms, commercial, showcase and kitchen unit fluorescent fixtures with incandescent spotlights to match. Also fluorescent bed lamps in various colors and swivel head desk lamps.

Two New SUNBEAM *Fixtures*



Models L-1502 & L-1504. 2 and 4 lamp 40 watt fully enclosed, hinged louvre bottom and remote starters, with 150 watt spotlights to match. Also furnished for individual mounting—flush or suspended.



Models 4003 and 4004. 3 and 4 lamp 40 watt fully enclosed, with curved Gleason Tiebout or Corning albalite lenses. Hinged frame and remote starters for easy maintenance. Also furnished for individual mounting—flush or suspended.

SYLVANIA ELECTRIC PRODUCTS, INC.

500 Fifth Avenue, New York 18, N. Y.

To meet requirements more efficiently and promptly,
Sylvania maintains offices in these cities:

ATLANTA, GA.
685 Whitehall St., S.W.

BOSTON 9, MASS.
10 Post Office Square

BUFFALO 17, N.Y.
778 Starin Ave.

CHICAGO 3, ILL.
Opera Bldg.
20 N. Wacker Drive

CLEVELAND 14, OHIO
East 9th St. & Euclid Ave.

DETROIT 2, MICH.
613 Boulevard Bldg.

KANSAS CITY 8, MO.
2109–11 Broadway

LOS ANGELES 13, CALIF.
210 W. 7th St.

NEW YORK 18, N.Y.
500 Fifth Avenue

PHILADELPHIA 7, PA.
Lincoln-Liberty Bldg.
Broad & Chestnut Sts.

SAN FRANCISCO 4, CAL.
111 Sutter Street

SEATTLE 1, WASH.
Stuart Bldg.
4424 White-Henry

WASHINGTON 5, D.C.
719 Fifteenth St., N.W.

Merchandising Headquarters
Lighting Division

Ipswich, Mass.
Fixtures

Salem, Mass.
Lamps

Sylvania Fluorescent Fixtures and Lamps, and Incandescent Lamps are engineered and manufactured for long life and efficient service in every type of application. Every Sylvania Fluorescent fixture is a "complete package of light"—engineered and shipped ready to mount, with the *complete* fixture guaranteed by Sylvania. They are available in basic models for industrial and commercial applications. The commercial fixtures offer complete flexibility for most general lighting applications.

The importance of simplified maintenance of equipment has been taken into account, with the result that it is not necessary to remove a single nut or screw in any industrial or commercial fixture to change lamps or starters.

"All Illumination Data, Maintenance Factors, from test by Sylvania Electric Products, Inc. Laboratories."

SYLVANIA ELECTRIC PRODUCTS, INC.

SYLVANIA ELECTRIC FIXTURES FOR HOMES, STORES, OFFICES, SCHOOLS, FACTORIES, INSTITUTIONS

Reflectors. 20-gauge steel with baked white enamel Miracoat finish; reflection factor 86%. No screws to remove when cleaning reflector which is held in alignment by retaining grooves in top housing.

Lamps. All models employ Sylvania fluorescent lamps.

Starters. All fixtures are supplied with one replaceable Sylvania Starter per lamp. Starters are located in the top housing of the fixtures for easy access.

High-Power Factor Ballasts. The power factor of all the 40-watt lamp-type ballasts supplied with these fixtures is not less than 95% in 2-lamp and 90% in 3-lamp fixtures. Ballasts are enclosed in top housings and operate the lamps out of phase to minimize stroboscopic effect.

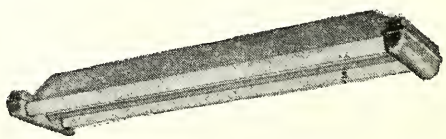
Operating Voltage. Standard models are available for 110–125 v., 60-cycle A.C., or for 220–250 v., 60-cycle A.C. Other standard voltages and frequencies to order.

Mounting. All commercial and industrial models shown can be mounted singly or end-to-end in continuous rows. All industrial models can be surface mounted or pendant suspended. Pendant suspension may be direct, with chain or conduit; or adjustable with Sylvania Slide Grip Hangers which can be attached at almost any point along the channeled top housings to overcome ceiling obstructions.

Equipment. All models bear the underwriter's inspection label and come to you equipped with Sylvania Fluorescent Lamps; Rotary Lock Type Lampholders, Starters, and Ballasts, completely wired and ready for installation.

Cat. No.	Lamps	Efficiency	Maintenance Factor	Maximum Spacing* Ratio
C-205	2 40-watt	62%	Good 70% Medium 62% Poor 55%	1.0
C-240	2 40-watt	86%	Good 75% Medium 67% Poor 60%	1.0
CL-240	2 40-watt	69%	Good 70% Medium 62% Poor 55%	0.9
HF-100	2 40-watt	85%	Good 70% Medium 55% Poor 40%	1.0
HFF-308	6 40-watt	85%	Good 65% Medium 52% Poor 40%	1.0
C-100	2 40-watt	87%	Good 75% Medium 67% Poor 60%	1.0
C-101	2 40-watt	74.2%	Good 70% Medium 60% Poor 50%	1.0

* The ratio of distance between units or continuous rows of units to the mounting height of the unit (from the floor).



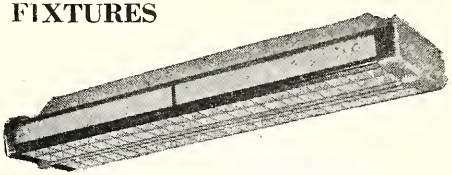
C-240 Unshielded, for individual or continuous row surface mounting. Two 40-watt Sylvania fluorescent lamps. COP 40 starter standard. Pendant set available for suspension.
C-440—same design with four 40-watt lamps.

Overall length.....49½″.
Overall width.....10½″.
Overall height.....4½″.
Shipping weight...27 lbs.

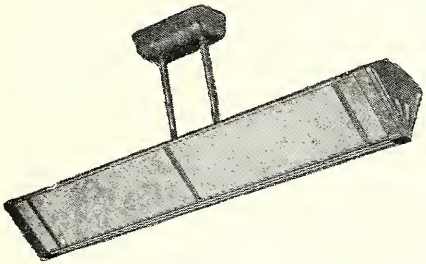
SYLVANIA ELECTRIC PRODUCTS INC.

FLUORESCENT FIXTURES

CL-240 Louver and glass panel shielded, for individual or continuous mounting. Two 40-watt Sylvania fluorescent lamps. COP 40 starter standard. Overall length, $49\frac{1}{8}$″. Overall width, $11\frac{3}{4}$″. Overall height, $7\frac{1}{8}$″. Shipping weight, 48 lbs. Pendant set available for suspension.



CL-440—same fixture design with four 40-watt lamps.

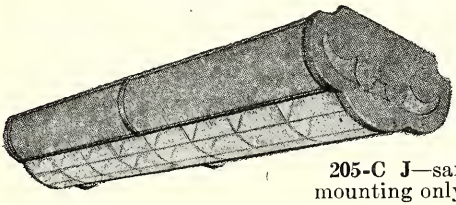


CP-150 Adjustable beam incandescent spotlight fixture for individual surface mounting or in rows of either C-240 or C-440 fixtures. One 150-watt Par 38 Pyrex incandescent spot or floodlight lamp. Overall length, $14\frac{5}{8}$″. Overall width, $10\frac{1}{2}$″. Overall height $7\frac{3}{8}$″. Shipping weight, 7 lbs. Pendant set available for suspension.



C-101 Glass shielded, for individual pendant suspension only. Two 40-watt Sylvania fluorescent lamps. Overall length, 49″. Overall width, $12\frac{9}{16}$″. Overall height, 8″. Shipping weight, 44 lbs.

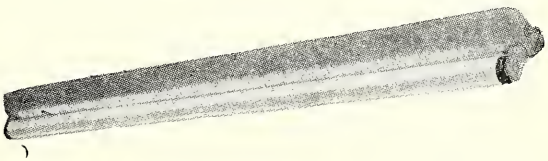
C-101 J—same fixture for continuous row pendant suspension only. C-115—C-115 J same basic design as C-101, for surface mounting individually or in continuous row.

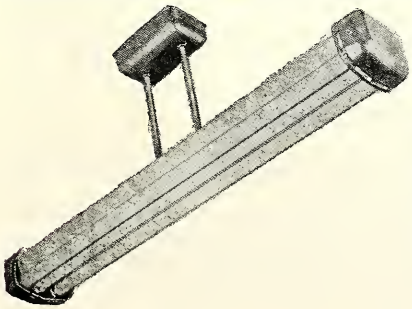


C-205 Plastic and louver shielded—for individual surface mounting. Four Sylvania fluorescent lamps. COP 40 starter standard. Overall length, $49\frac{9}{16}$″. Overall width, 14″. Overall height, $7\frac{1}{4}$″. Shipping weight, 50 lbs.

205-C J—same fixture for continuous-row surface mounting only. Accessories for suspension available.

CS-140 Unshielded utility strip for surface mounting individually or in continuous rows. One 40-watt Sylvania fluorescent lamp. Overall length, $48\frac{3}{32}$″. Overall width, $3\frac{1}{8}$″. Overall height, $3\frac{3}{4}$″. Shipping weight, $8\frac{1}{2}$ lbs. Also available are similar strips, CS-120 and CS-115, employing 15 and 20-watt lamp.



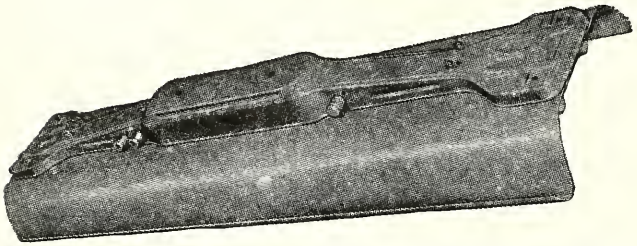


C-100 Unshielded, for individual pendant suspension only. Two 40-watt Sylvania fluorescent lamps. Overall length, $50\frac{3}{8}$″. Overall width, $7\frac{3}{4}$″. Overall height, $5\frac{1}{2}$″. Shipping weight, 32 lbs.

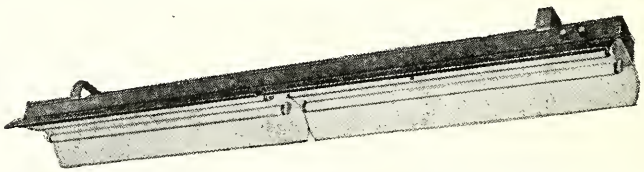
C-100 J—same fixture for continuous-row pendant suspension only. C-113 and C-113 J same fixture design for individual or continuous-row surface mounting only.

SYLVANIA ELECTRIC PRODUCTS, INC.

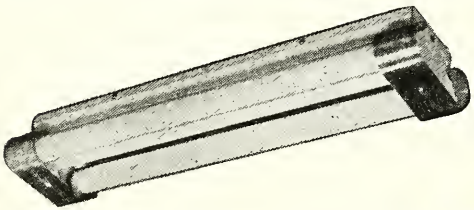
FLUORESCENT FIXTURES



HF-100 With streamlined top housing, for individual and continuous row surface mounting or suspension. Two 40-watt Sylvania fluorescent lamps. Overall length, 49¾″. Overall width, 14⅞″. Overall height, 6$\frac{13}{16}$″. Shipping weight, 28 lbs. Also available are units of similar design, HF-150, with three 40-watt lamps, and HF-235, with two 100-watt lamps.



HFF-308 With double-length channel top-housing and two slide grip hangers. Recommended for continuous-row use. Six 40-watt Sylvania fluores-cent lamps. Overall length, 104¾″. Overall width, 14⅞″. Shipping weight, 80 lbs. Total wattage, 300.
HFF-308 J—same unit, for continuous-row use only.





R-422 A fluorescent fixture to meet the demand of home owners, architects, builders and contractors. Employs 4 20-watt fluorescent lamps. Installed on any existing ceiling outlet which utilizes standard 110–125 v., 60 cycle AC. Shipping wt. 19 lbs.
RW-160 Residential unit designed for decorative lighting. Uses one 6-watt fluorescent lamp shielded by a curved glass diffusing panel. RW-160 is designed for permanent installation over a standard wall box. RWC-160 (with cord) is pinup unit that can be plugged into any outlet. Both types are supplied with switch for manual starting. Approximately 10″ high. Old ivory or light bronze finish. Shipping weight 3 lbs.

Note: This is a representative grouping of Sylvania fixtures. Information on complete line available on request.

SYLVANIA FLUORESCENT LAMPS

Sylvania Fluorescent lamps are famous for *smooth coating* which means more light output and more uniform light. All lamps of a specified color are precisely the same shade.

Daylight, White and Soft White and 4500° White, are indicated in following chart by /D, /W, /SW and /45W. Lamps are also available in Pink, Blue, Green, Red and Gold. Length of lamps is indicated in column 3 (Bulb). The numeral following the T in the first and third column is outside diameter in ⅛″. Example: F675/D—6-watt, ⅝″ diam., daylight.

SYLVANIA ELECTRIC PRODUCTS INC.

FLUORESCENT LAMPS (cont.)

Lamp Ordering Abbreviation	(A) Approx. Lamp Watts	Bulb	Base	Burning Hours Per Start	(B) Rated Average Life Hours	Approx. Initial Lumens	Starter Required
F6T5/D	6	9″T5	Min. Bipin	3	2500	815	FS-5
F6T5/W	6	"	"			210	
F6T5/45W	6	"	"			200	
F8T5/D	8	12″T5	"	3	2500	295	TS-5
F8T5/W	8	"	"			330	
F8T5/45W	8	"	"			310	
F13T5/D	13	21″T5	"	3	2500	490	FS-4
F13T5/W	13	"	"			580	or
F13T5/45W	13	"	"			550	M-4
F14T12/D	14	15″T12	Med. Bipin	3	2500	405	Manual,
F14T12/W	14	"	"			490	FS-2 or
F14T12/SW	14	"	"			350	COP-20
F14T12/45W	14	"	"			460	
F15T8/D	15	18″T8	"	3	2500	525	FS-2,
F15T8/W	15	"	"	6	4000	630	M-2 or
F15T8/SW	15	"	"	12	6000	495	COP-20
F15T8/45W	15	"	"			570	
F15T12/D	15	18″T12	"	3	2500	495	FS-2,
F15T12/W	15	"	"	6	4000	600	M-2 or
F15T12/SW	15	"	"	12	6000	480	COP-20
F15T12/45W	15	"	"			570	
F20T12/D	20	24″T12	"	3	2500	800	FS-2,
F20T12/W	20	"	"	6	4000	960	M-2 or
F20T12/SW	20	"	"	12	6000	740	COP-20
F20T12/45W	20	"	"			860	
F30T8/D	30	36″T8	"	3	2500	1350	FS-4,
F30T8/W	30	"	"	6	4000	1500	M-4 or
F30T8/SW	30	"	"	12	6000	1170	COP-30
F30T8/45W	30	"	"			1380	
F40T12/D	40	48″T12	"	3	2500	2000	FS-4,
F40T12/W	40	"	"	6	4000	2320	M-4 or
F40T12/SW	40	"	"	12	6000	1800	COP-40
F40T12/45W	40	"	"			2120	
F100T17/D	100	60″T17	Mog. Bipin	3	3000	3900	M-6
F100T17/W	100	"	"	6	4500	4400	COP-26
F100T17/SW	100	"	"	12	6500	3400	M-64
F100T17/45W	100	"	"			4000	COP-64

(A) Wattage of lamps only. Add wattage loss of ballast to obtain total wattage.
(B) Average life under specified test conditions.

WIRING DEVICES (STARTERS)

COP Manual re-set starter immediately cuts out deactivated lamp and eliminates annoying flashing of lamp and danger to ballast. A push of the re-set button, when the new lamp is inserted, puts starter in operation.

SPEED GLOWSTAT Specially designed glow-type starter gives adequate preheating, less flashing. Provides ideal starting-time characteristics.

MIRASTAT An exclusive Sylvania design, this thermal starter insures long and satisfactory lamp performance. Restarting position provides quick restarting and adds extra life to the starter.

SYLVANIA ELECTRIC PRODUCTS INC.

WIRING DEVICES (cont.)

Cat. No.	For Use With	Std. Pkg.
COP-20	14, 15 and 20 watt lamps	100
COP-30	30 watt lamps	100
COP-40	40 watt lamps	100
COP-6	100 watt lamps	50
COP-64	100 watt lamps (4-contact type)	50

Cat. No.	For Use With	Std. Pkg.
FS-2	14, 15 and 20 watt lamps	100
FS-4	13, 30 and 40 watt lamps	100
FS-5	4, 6 and 8 watt lamps	50

Cat. No.	For Use With	Std. Pkg.
M-2	15 and 20 watt lamps	100
M-4	30 and 40 watt lamps	100
M-6	100 watt lamps	50
M-64	100 watt lamps (4-contact type)	50
M-7	65 watt lamps	20

LAMPHOLDERS

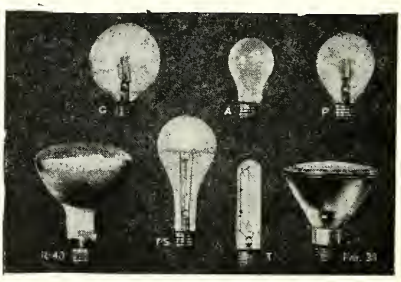
The new, improved Sylvania Fluorescent Lampholders are completely interchangeable with other rotary lock-type holders. There is a type for every size of fluorescent lamp.

Design Features: One-piece molded housing gives added strength at lamp-insertion points. Binding screws located in central position underneath are staked and backed out, making wiring easy, safe and neat. Combination models are built so starters always make positive contact with an easy twist.

No.	Lampholder
S-100	Miniature white (Standard)
S-100A	Miniature white (Special)
S-101	Miniature black (Standard)
S-101A	Miniature black (Special)
S-200	Medium white
S-201	Medium black
S-202	Medium white combination with starter socket
S-203	Medium black combination with starter socket
S-210	Medium channel-white (for 15 and 30-watts. T-8 only)
S-211	Medium channel-black (for 15 and 30-watts. T-8 only)
S-220	Medium but-on-white (Furnished with one 9-inch lead and one 27-inch lead)
S-221	Medium but-on-black (Furnished with one 9-inch lead and one 27-inch lead)
S-275	Medium black separate starter socket with 6″ No. 18 leads
S-300	Mogul white lampholder with mounting bracket
S-302	Mogul white combination with starter socket and mounting bracket
S-304	Mogul white lampholder without mounting bracket
S-306	Mogul white combination with starter socket and without mounting bracket
S-375	Mogul black separate starter socket with 6″ No. 18 leads
S-500	Long-slim—single contact spring end
S-502	Cold cathode—Single contact spring end
S-510	Long-slim — Double contact
S-512	Cold cathode—Double contact

SYLVANIA INCANDESCENT LIGHT BULBS

BULB DESIGNATIONS. Bulb shapes are indicated by a letter and a number. The letter shows the shape of the bulb, while figures show the diameter of the bulb at its widest part in eighths of an inch. (G-30, for example, means a globe-shaped or round bulb 30-eighths of an inch, or $3\frac{3}{4}$″ in diameter.)



RATED AVERAGE LIFE. The standardized life of Sylvania Light Bulbs is 1000 hours. Some particular types, however, may have a shorter or a longer life. The purpose for which the light bulb is used, the balance between the amount of light produced and the cost of operation are factors in determining average life.

SYLVANIA ELECTRIC PRODUCTS INC.

INCANDESCENT LIGHT BULBS (Cont.)

OTHER SIZES. The Light Bulbs listed here are those in common use. Many of the items are supplied in other sizes and finishes.

In addition, Sylvania makes a complete line of photoflash lamps and many other types for special purposes, such as Street Lighting, Traffic Signal, Locomotive Headlight, etc. The complete line of all Standard Sylvania Light Bulbs is shown in our catalog, available on request.

STANDARD INSIDE FROSTED

115, 120 and 125 volts

Watts	Bulb	Base	Overall Length	Standard Package	Finish
15	A-15	Med.	$3\frac{1}{2}$	120	
25	A-19	Med.	$3\frac{15}{16}$	120	
40	A-19	Med.	$4\frac{1}{4}$	120	
50	A-19	Med.	$4\frac{7}{16}$	120	IF
60	A-19	Med.	$4\frac{7}{16}$	120	
75	A-21	Med.	$5\frac{5}{16}$	120	
100	A-21	Med.	$5\frac{5}{16}$	120	

If used out of doors, the 40, 60, and 100 watt lamps, which are gas filled, should be protected from rain and snow.

230 and 250 volts, Inside Frosted

25	A-19	Med.	$3\frac{15}{16}$	120	
*50	A-19	Med.	$3\frac{15}{16}$	120	IF
100	A-21	Med.	$6\frac{1}{16}$	120	

* For mine lighting the 50 watt lamp is supplied in 285 volts at a list price of 33 cents.

LARGE WATTAGE

115, 120 and 125 volts

Watts	Bulb	Base	Overall Length	Standard Package	Finish
150	PS-25	Med.	$6\frac{15}{16}$	60	C-WB-IF
200	PS-30	Med.	$8\frac{1}{16}$	60	C-WB-IF
300	PS-35	Med.	$8\frac{3}{4}$	24	C-IF
300	PS-35	Mog.	$9\frac{3}{8}$	24	C-WB-IF
500	PS-40	Mog.	$9\frac{3}{4}$	12	C-WB-IF
750	PS-52	Mog.	$13\frac{1}{16}$	6	C-IF
1,000	PS-52	Mog.	$13\frac{1}{16}$	6	C-IF
1,500	PS-52	Mog.	$13\frac{1}{16}$	6	C

The clear 750, 1,000 and 1,500 watt 115-125 volt lamps are also suitable for floodlighting service.

3-LIGHT

Give three levels of illumination. Requires special socket. Particularly built for I.E.S. reading lamps. Inside frosted.

115, 120 and 125 volts

Watts	Bulb	Base	Overall Length	Standard Package	Finish
50–100–150	PS-25	3-contact Mogul	$6\frac{13}{16}$	60	IF
100–200–300	G-30	3-contact Mogul	$6\frac{3}{4}$	24	

SYLVANIA SUPERLITE (OPAL)

115, 120 and 125 volts

Watts	Bulb	Base	Overall Length	Standard Package
15	A-15	Med.	$3\frac{1}{2}$	120
25	A-19	Med.	$3\frac{15}{16}$	120
40	A-19	Med.	$4\frac{1}{4}$	120
60	A-19	Med.	$4\frac{7}{16}$	120
100	A-21	Med.	$5\frac{5}{16}$	120
150	PS-25	Med.	$6\frac{15}{16}$	60
200	PS-30	Med.	$8\frac{1}{16}$	60

SIGN AND DECORATIVE

115, 120 and 125 volts

Watts	Bulb	Base	Overall Length	Standard Package	Finish
6	S-6	Cand.	$1\frac{7}{8}$	120	C
10	S-11	Inter.	$2\frac{5}{16}$	120	C-IC
10	S-14	Med.	$3\frac{1}{2}$	120	C-IF-IC
25	A-19	Med.	$3\frac{15}{16}$	120	IC

TUBULAR

115, 120 and 125 volts

Watts	Bulb	Base	Overall Length	Standard Package	Finish
25	T-10	Med.	$5\frac{5}{8}$	60	C-IF
25	T-10	Med.	$5\frac{5}{8}$	60	IF-Reflector
40	T-10	Med.	$5\frac{5}{8}$	60	C-Reflector
40	T- 8	Med.	$11\frac{7}{8}$	24	C
25	T- $6\frac{1}{2}$	Inter.	$5\frac{1}{2}$	60	C

SYLVANIA BIRDSEYE INFRARED HEAT

115–125 volts

Watts	Bulb	Base	Standard Package	Finish
250	R-40	Med.	12	IF

Designed for intermittent burning in household application. Also complete line of Infrared bulbs for Industrial use.

COUNTRY HOME

*30 volts

Watts	Bulb	Base	Overall Length	Standard Package	Finish
15	A-17	Med.	$3\frac{5}{8}$	120	
25	A-19	Med.	$3\frac{15}{16}$	120	IF
50	A-21	Med.	$4\frac{15}{16}$	120	
100	A-23	Med.	$6\frac{1}{16}$	120	

* 34 volt lamps take a list price of 4 cents, additional.

VIBRATION SERVICE

For use in industrial service to combat jar or vibration. Should be used only where standard lamps fail to stand up.

115, 120 and 125 volts

Watts	Bulb	Base	Overall Length	Standard Package	Finish
50	A-19	Med.	$3\frac{15}{16}$	120	IF
100	A-23	Med.	$6\frac{1}{16}$	120	

LUMILINE

In effect tubes or lines of light, giving the impression of one continuous line of light. Use a special contact cap instead of usual base.

115, 120 and 125 volts

Watts	Bulb	Base	Overall Length	Standard Package	Finish
30	T-8	Disc.	$17\frac{3}{4}$	24	C-IF
40	T-8	Disc.	$11\frac{3}{4}$	24	IC White or Straw
60	T-8	Disc.	$17\frac{3}{4}$	24	

SYLVANIA ELECTRIC PRODUCTS INC.

INCANDESCENT LIGHT BULBS (cont.)

DAYLIGHT

Give light of a quality which will ordinarily make colors appear about as in daylight. Especially useful in show windows, department stores, printing offices, or wherever colors have to be matched.

115, 120 and 125 volts

Watts	Bulb	Base	Overall Length	Standard Package	Finish
60	A-19	Med.	$4\frac{7}{16}$	120	IF
100	A-23	Med.	$6\frac{1}{16}$	120	

ROUGH SERVICE

For extension cord service in machine shops, garages, on dredges, shovels and derricks, and in similar places where lamps are subject to abuse. Should be used only where standard lamps fail to stand up. Inside frosted.

115, 120 and 125 volts

Watts	Bulb	Base	Overall Length	Standard Package	Finish
50	A-19	Med.	$3\frac{1}{16}$	120	IF
100	A-23	Med.	$6\frac{1}{16}$	120	

SILVERED BOWL

Watts	Bulb	Base	Overall Length	Standard Package	Finish
60	A-19	Med.	$4\frac{7}{16}$	120	Silvered Bowl over IF
100	A-23	Med.	$6\frac{1}{16}$	120	

Send for further information about the Sylvania Birdseye Line of Spot and Floodlight bulbs.

PROJECTION BLUBS

115, 120 and 125 volts

Watts	Bulb	Base	Service	Light Center Lgth.	Overall Lgth.	Std. Pkg.	Finish
100	P-25	Med.	Spot-light	3	$4\frac{3}{4}$	60	
250	G-30	Med.	Spot-light	3	$5\frac{1}{8}$	24	
250	G-30	Med.	Flood-light	3	$5\frac{1}{8}$	24	
400	G-30	Med.	Spot-light	3	$5\frac{1}{8}$	24	
500	G-40	Mog.	Flood-light	$4\frac{1}{4}$	$7\frac{1}{16}$	12	C
1,000	G-40	Mog.	Flood-light	$5\frac{1}{4}$	8	12	
1,000	G-40	Mog.	Spot-light	$4\frac{1}{4}$	$7\frac{1}{16}$	12	

Send for further information about the Sylvania Birdseye Line of Spot and Floodlight Bulbs.

SYLVANIA BIRDSEYE REFLECTOR LAMPS

SPOTLIGHT

Watts	Bulb	Class & Fil.	Life	Base	Standard Pkg. Quan.
75	BR32½	C-M	1000	Med.	24
100(1)	BR40	C-M	1000	Med.	12
150(1)	BR40	C-M	1000	Med.	12
200(1)	BR40	C-M	1000	Med.	12
300(1)	BR40	C-M	1000	Med. Skt.	12
500	BR59	C-N	1000	Mog. Skt.	6

These lamps are constructed from special type bulbs which have a special inside frost. The wattages marked (1) in above chart indicate availability in clear glass bulbs.

TUBULAR

Watts	Bulb	Class & Fil.	Life	Base	Standard Pkg. Quan.
25	T10	C-CC8	1000	Med.	60
40	T10	C-CC8	1000	Med.	60

These lamps have Sylvania's "coil-within-coil" filament, providing more concentrated, brilliant light with great efficiency and economy.

FLOODLITE

Watts	Bulb	Class & Fil.	Life	Base	Standard Pkg. Quan.
100	R40	C-M	1000	Med.	12
150	R40	C M	1000	Med.	12
200(1)	R40	C-M	1000	Med.	12
300(1)	R40	C-CC2V	1000	Med.	12

Sylvania Birdseye Floodlite Lamps' peak beam distribution is approximately 60°. Note: (1) Burn only in porcelain sockets.

CONCENTRATOR

Watts	Bulb	Class & Fil.	Life	Base	Standard Pkg. Quan.
100	PS30	C-M	1000	Med.	24
150	PS30	C-M	1000	Med.	24
200	PS35	C-M	1000	Med.	24
300	PS40	C-M	1000	Mog.	12
300	PS40	C-M	1000	Med. Skt.	12
500	PS52	C-M	1000	Mog.	6

The beam from this lamp is narrow, thereby giving a big light dividend in additional "punch" for special applications.

SUPER SPOT

is designed to provide a highly concentrated beam especially useful in highlighting a single object in a display. It may be used individually in store windows or interior displays, or it may be used in groups or lines to illuminate counters and larger display pieces. Made in 4 sizes from 100 to 300 watts inclusive.

Watts	Bulb	Class & Fil.	Life	Base	Standard Pkg. Quan.
100	R40	C-M	1000	Med.	12
150	R40	C-M	1000	Med.	12
200(1)	R40	C-M	1000	Med.	12
300(1)	R40	C-CC2V	1000	Med.	12

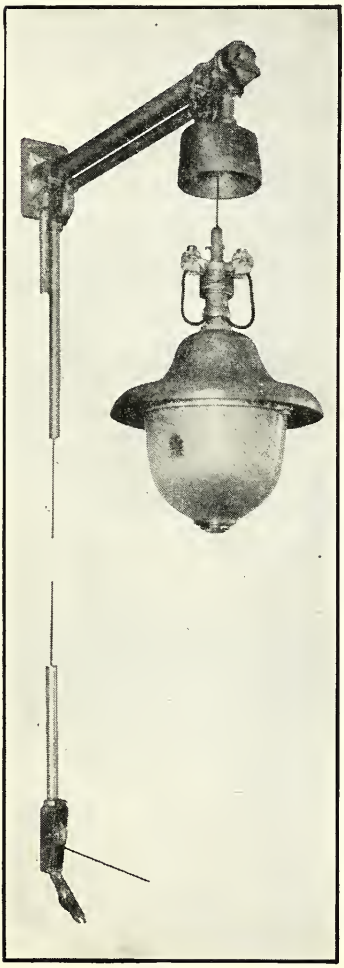
Because it provides such a high intensity of illumination in a small area Super Spot is not recommended for general lighting. For those wattages marked (1) in chart above only porcelain sockets are recommended.

THE THOMPSON ELECTRIC CO.

1101-11 Power Avenue, Cleveland 14, Ohio, U. S. A.

Manufacturers of Thompson Disconnecting and Lowering Hangers
Shock Absorbers, Suspension Devices and Accessories for Lighting Equipment

The Thompson Hanger is essentially a positive positioning latching type, overhead disconnecting switch, and a fixture lowering and raising device combined. It consists of two members, upper and lower.



In the above illustration, the hand line has been attached, the Hanger disconnected and partially lowered. This installation utilized Unit Package UPBL-177-1½. Operation is the same regardless of height.

The upper member, carrying a pair of upper contact assemblies, to which the feed wires attach, is firmly secured to the supporting structure.

The lower member carries the engaging lower contact assemblies, wired to the lighting unit, which it supports.

The entire operation is a simple manual one by means of the regulated pull and release on the small chain or cable used to lower and raise the luminaire.

Thompson Hangers provide the means for complete, safe, low cost servicing of lighting equipment at floor or ground level. They are suitable for many types of lighting equipment such as incandescent, mercury, including the 3 K.W., fluorescent and cold cathode.

A variety of models are available for indoor and outdoor use, to meet the wide range of installation requirements. Complete Unit packages are also available for pole and wall bracket, mounting, pendant units and floodlights. They are also available for aeronautical Obstruction Lights, and 300 MM. Code Beacons.

Thompson Hangers are available in the two pole type for both indoor and outdoor use, Underwriters approved and rated 15 Amps. 600 Volts; 30 Amps. 250 Volts, ac, 20 Amps. 250 Volts dc.

Also the four pole type for indoor use only, suitable for 2 circuits each 2 wires; 2 circuits 3 wires, or 3 circuits 4 wires, rated 15 Amps. 115 Volts; 7½ Amps. 230 volts, ac each circuit.

Thompson Hangers are particularly desirable for servicing lighting equipment mounted 16 feet or more above floor or ground level, in Armories, Auditoriums, Field Houses, Gymnasiums, Swimming Pools, Banks, Churches, Libraries, Lodge Halls, Industrial Plants of many types, Outdoor Floodlighting on poles or masts (small groups of 6 or less), Parking Lots, Service Stations, Plant Yards, and Aeronautical Obstruction Lighting on stacks, poles, masts, water tanks and other structures.

ERROR
Catalog 47, Page 8, 2nd Line of Table Column headed "Indoor Models" Model No. L-341 should be L-321.
Please correct.

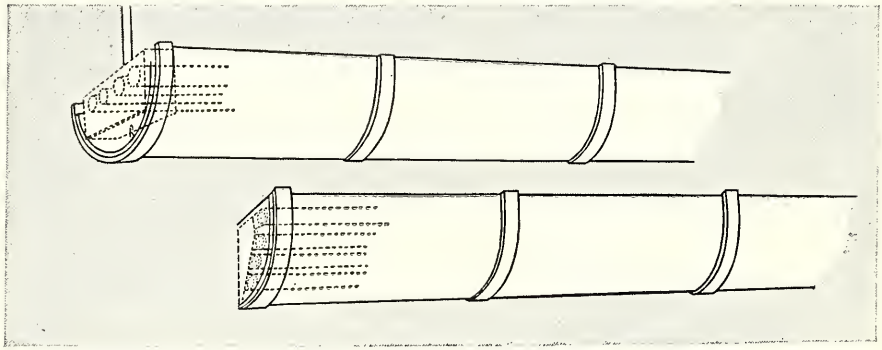
VOIGT COMPANY

1649 North Broad Street, **Philadelphia 22, Penna.**

Illuminating Engineers - Decorative Metal and Glass Craftsmen

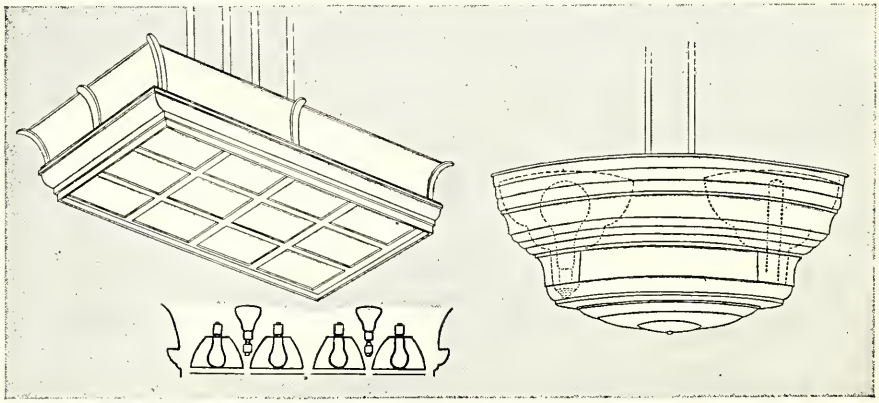
Lighting Equipment

Voigt Company offer design and engineering service as well as manufacturing facilities for the production of special Architectural Lighting Equipment for Public Buildings. Sketches below illustrate typical designs, each using a different light source. Inquiries Solicited.



No. 10185—Semi-Indirect, Cold Cathode, Continuous fluorescent ceiling luminaire for 96″ lamps; bent white alabaster glass.

No. 10257—Semi-Indirect, Hot Cathode, Continuous fluorescent wall luminaire for 96″T-8 Slimline lamps; bent Corning Alba-Lite glass.



No. 10143-B—Indirect Semi-Indirect, Incandescent Pendant Luminaire. Ornamental Bronze, Holophane Controlens and flashed opal bent glass. Section shows arrangement of PS-30, 200 watt lamps with prismatic reflector and Controlens for downlighting; R-40 Reflector lamps for upward illumination.

No. 10242—Indirect Mercury and Incandescent combination luminaire. Spun Aluminum housing; Alzak reflectors with dust tight cover glass for 2 A-H1 400 watt mercury lamps and 2 PS-52, 1500 watt incandescent lamps. Mercury transformer housed in ceiling canopy of luminaire.

VOIGT COMPANY

1649 North Broad Street, Philadelphia 22, Penna.

Lighting Equipment

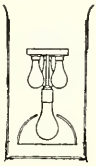
Designers
Manufacturers
Distributors

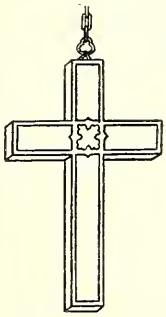
Voigt Company offer standard lighting equipment for Churches, Theatres, Banks, Hotels, restaurants, stores, institutional buildings, etc. Sketches below illustrate typical designs. Standard design data available on request. Specify requirements.



No. 9976-E Gothic Church Lantern. Art glass panels in sides; prismatic glass in bottom.

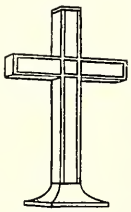
Cross-section view of lighting arrangement, 2 circuit wiring; #1 circuit with reflector furnishes down light; #2 circuit, soft dim lighting. Bottom panel on drop hinge for easy cleaning and relamping.

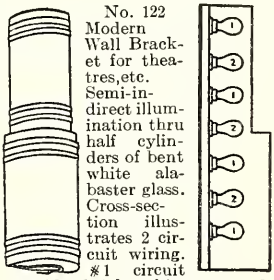




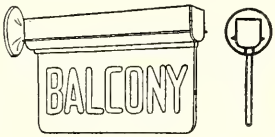
No. 0923-G Illuminated Chancel Cross. Pendant ceiling type.

No. 6927-B Illuminated Table Cross.





No. 122 Modern Wall Bracket for theatres, etc. Semi-indirect illumination thru half cylinders of bent white alabaster glass. Cross-section illustrates 2 circuit wiring. #1 circuit provides bright white or toned amber light for general lighting; #2 circuit (alternating lamps) soft color lighting during show.



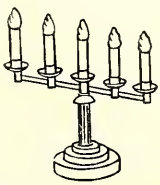
No. 110 edge-lighted direction sign for T-8 or T-10 lamp. Available single or double face; extended wall, flat wall or ceiling mounting; any lettering.



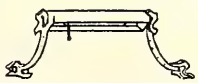
No. 128-X flush type sign for A or S type lamp inside metal box which is recessed in wall; opening 12 x 6½ x 3″ deep required; lettering Exit, Ladies, Men or silhouettes as on 128LP.



No. 128-LP surface type sign for A or S type lamp inside metal housing; size 16½ x 7 x 3½″ extension. Flat wall mounting; lettering Exit, Ladies, Men or Ladies and Men Silhouettes.



No. 7873-J Electric Candelabra.



No. 6169-H Pulpit or Lectern Lamp.

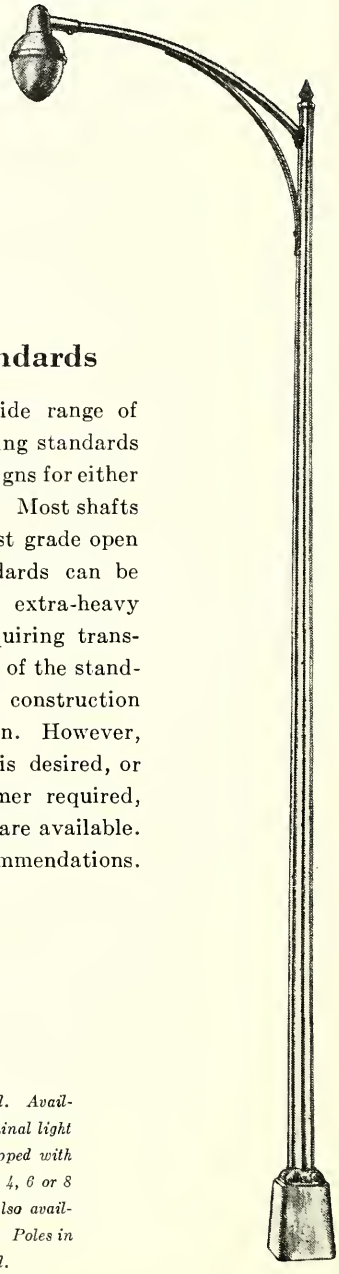


No. 148-M edgelighted sign for A or S type lamp inside metal housing. Flat wall surface mounting; lettering Men, Ladies, Exit, etc. sandblasted on plate glass. Other styles available.

The Union Metal Manufacturing Co.

Canton 5, Ohio

Designers and producers of steel Monotube street, bridge and highway lighting standards, floodlighting poles and other fabricated steel products.



Street Lighting Standards

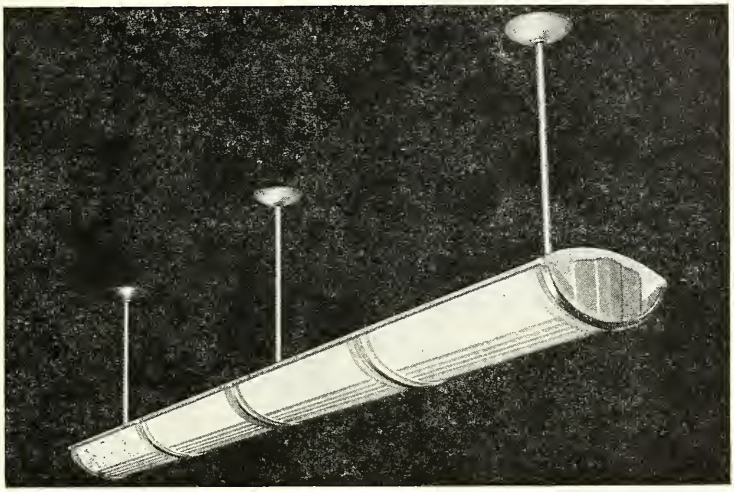
Union Metal manufactures a wide range of tapered, tubular *steel* street lighting standards in both fluted and plain round designs for either overhead or underground wiring. Most shafts are fabricated from 11 gauge, best grade open hearth steel, but special standards can be supplied in heavier gauges for extra-heavy duty. For installations not requiring transformers or auxiliaries in the base of the standard, Union Metal's anchor base construction provides a neat, inexpensive design. However, when additional ornamentation is desired, or the use of cutout or transformer required, standards with transformer base are available. All designs conform to I.E.S. Recommendations.

Latest Union Metal street lighting standard. Available in standardized heights to reach nominal light centers of 20, 25, 30, 35 and 40 feet. Equipped with new 45-degree upsweep type brackets in 4, 6 or 8 foot lengths with supporting scrolls. Also available with 10, 12, 15 and 18 foot mast arms. Poles in two styles—octaflute or plain round.

THE F. W. WAKEFIELD BRASS COMPANY

Vermilion, Ohio

Over-ALL Lighting by *Wakefield*



The Star

THE STAR

Desirable illumination for offices, drafting rooms and schools is provided by indirect illumination wherein the brightness of the reflector is approximately equal to the brightness of the ceiling. This kind of lighting is provided by the STAR, a new luminous indirect lighting unit. The STAR makes use of a molded translucent Plaskon reflector of such density that the lighted luminaire is of almost the same brightness as the illuminated ceiling. When STAR units are used continuously, mounted and spaced in accordance with our engineering specifications, an evenly lighted ceiling is achieved, with no deep shadows or sharp contrasts and without distracting glare from the light source. This is the new "Over-ALL Lighting" by Wakefield.

The STAR makes use of two 40-watt fluorescent lamps, which are accessible from the top of the reflector. The reflectors are held in place by illuminated satin aluminum supporting bands.

The molded reflectors and end caps are made from Plaskon. The reflectors are light in weight, non-electrostatic, non-shatterable, uniform in appearance and will not support combustion. All visible metal parts are finished in satin aluminum.

Typical Results

Drafting Room:	38′ x 28′	Reflection Factor: Ceiling	75% Acoustic Tile
		Walls	60% Light Yellow
Lamps:	3500° White		
		Brightness:	
Loading:	4.7 Watts per sq. ft.	Luminaire Reflector	120 foot-lamberts
Spacing 5′ on centers		Ceiling over Luminaire	170 foot-lamberts
Average Illumination:		Ceiling between	
65 fc. I.E.S. Standard Method		Luminaire	70 foot-lamberts
		Side wall at eye level	40 foot-lamberts
		End wall	25 foot-lamberts

Source: I.E.S. Data Sheet No. 13-53

THE F. W. WAKEFIELD BRASS COMPANY

Over-All Lighting by Wakefield, Vermilion, Ohio

THE STAR

Minimum Requirement for Satisfying Lighting Performance.

The STAR is a fine piece of engineered lighting equipment but misapplication will result in dissatisfaction. Therefore, the same consideration should be given its installation as when any other important addition or investment is made to the office, drafting room, or school. The following table sets up the minimum requirements for fine lighting results:

Minimum Room Area:	12′ x 24′
Ceiling Height:	10′ to 14′
Ceiling Conditions:	Clean or newly painted with reflections above 75%.
Side Walls:	Pastel colors of reflection not less than 50%.

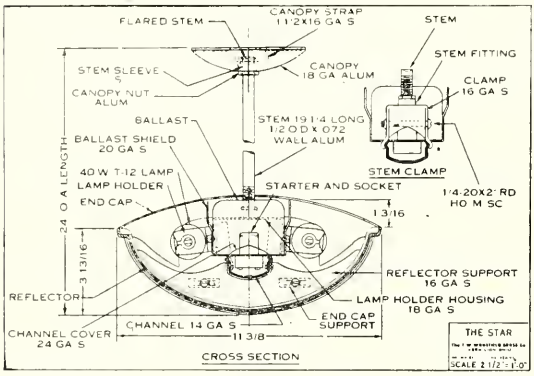
If the above conditions are present, the following table may be used in determining footcandle results:

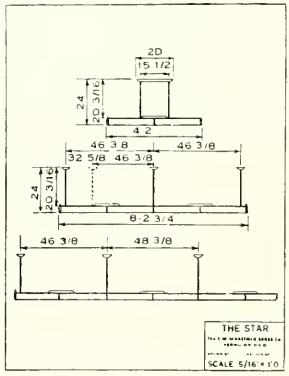
CONTINUOUS ROW INSTALLATIONS

	Room Index A	Large Room 48′ x 96′	Room Index D	Medium Room 24′ x 48′	Room Index G	Small Room 12′ x 24′
Spacing	No. of Rows	Footcandles	No. of Rows	Footcandles	No. of Rows	Footcandles
4′ 0″	12 of 22*	79	6 of 10*	58	3 of 5*	43
4′ 4″	11 of 22	72				
4′ 9″	10 of 22	66	5 of 10	48		
5′ 3″	9 of 22	59				
6′ 0″	8 of 22	52	4 of 10	38	2 of 5	29
6′ 9″	7 of 22	46				
8′ 0″	6 of 22	39	3 of 10	28		

* Units per Row.

Light distribution $\frac{63\frac{1}{2}\%}{7\frac{1}{2}\%}$



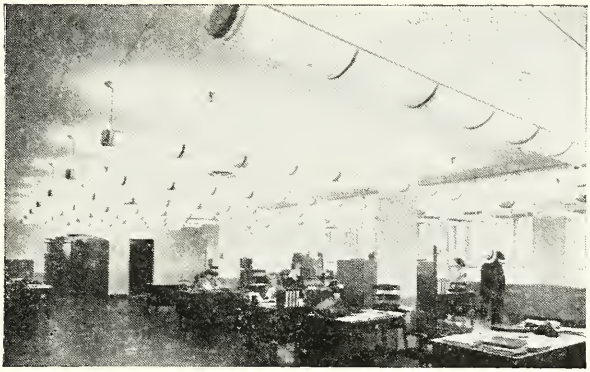


MAINTENANCE

All lighting equipment requires regular maintenance for efficient performance. The STAR should not be installed in any interior unless regular maintenance is available. Reflector sections may be easily removed from the unit for dusting, at intervals to be determined by the type of interior in which the equipment is used. The reflectors should be taken down and washed in warm water with mild soap as needed. Lamps and reflecting surfaces should likewise be kept clean.

THE F. W. WAKEFIELD BRASS COMPANY

Over-All Lighting by Wakefield, Vermilion, Ohio

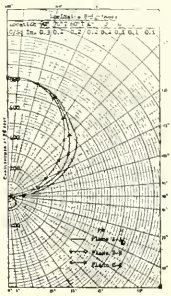


The STAR No. ST-248 With Twin Stems

SPECIFICATIONS

Continuous runs of the STAR may be made from parts consisting of bodies and reflectors, stems and end caps. When ordering continuous rows for a specific installation, the number of units in a run should be indicated by a numerical prefix to the catalog number; for example No. 6ST-248; No. 8ST-248. Necessary parts will be supplied to complete such a run from stock by using the following catalog numbers: No. 12 Double Stem Assembly, No. 14 Single Stem Assembly, No. ST-248-B Body, No. 15 End Caps, Clamps, Reflector Support and Lampholder, Housing Cap.

Units used singly in corridors or small rooms for matching design installation are equipped with twin stem suspension.



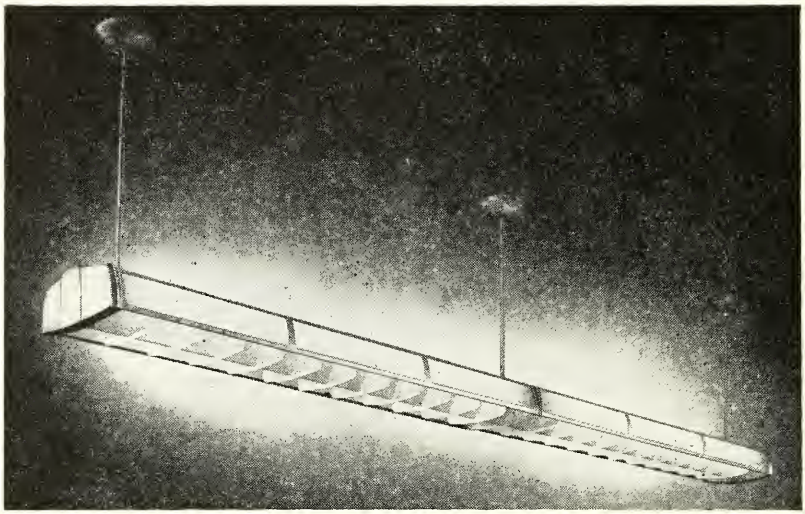
PHOTOMETRIC CHART

The flux or light of any lighting unit is plotted on a curve as a result of tests made by Electrical Testing Laboratories. Shown here is the distribution curve resulting from such a test of the STAR unit. A careful study of this data will demonstrate just what may be expected from an installation of STAR Units.

Catalog No.	Number of Lamps	Std. Susp.	Description	Standard Weight		Package Quantity
				Packed	Un-packed	
ST-248-B	2-40 W.	4″	Body and Reflectors only.	17	14	1
12		20″	Double Stem and Canopy Assembly.	3	2	1
14		20″	Single Stem and Canopy Assembly.	2	1	1
15			End Caps, Clamps, etc. "Ends of Run" Assembly.	2	1	1

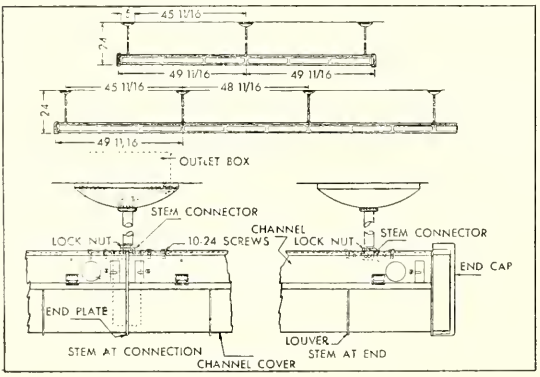
THE F. W. WAKEFIELD BRASS COMPANY

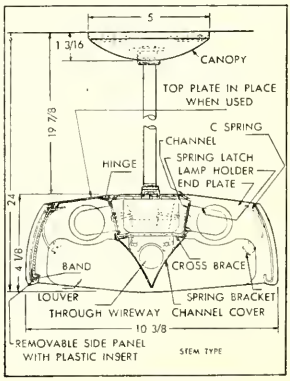
Over-All Lighting by Wakefield. Vermilion, Ohio



THE GRENADIER II

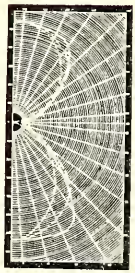
The Grenadier is a louvered unit with translucent plastic side panels utilizing two 40 W. fluorescent lamps in each 4′ section. It is made in three types: Stem (illustrated), Canopy and On Ceiling. All types interconnect for continuous runs. Louver provides 35° shielding normal to the lamp and 25° parallel. On the Stem and Canopy types, distribution of light may be regulated by selection of optional designs of top plate reflectors.





THE F. W. WAKEFIELD BRASS COMPANY

Over-All Lighting by Wakefield, Vermilion, Ohio

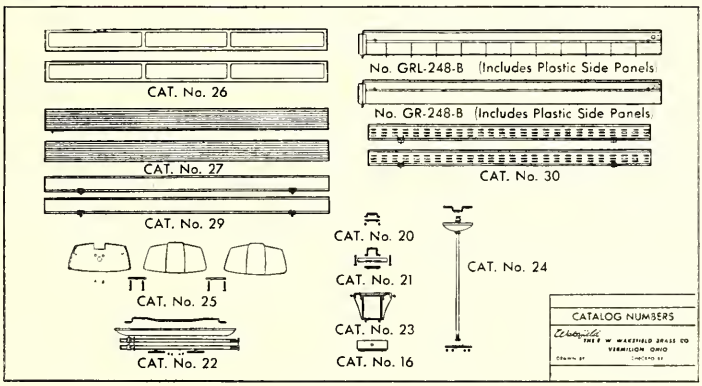


MF = 0.70

↑
38.3
42.0
↓

Ceiling	75%			50%			30%	
Walls	50%	30%	10%	50%	30%	10%	30%	10%
Room Index	Utilization Factors							
J	.28	.24	.22	.24	.22	.20	.20	.18
I	.34	.30	.29	.30	.27	.26	.25	.23
H	.38	.35	.32	.33	.30	.29	.28	.26
G	.41	.38	.36	.36	.34	.32	.30	.29
F	.44	.41	.38	.38	.36	.34	.32	.30
E	.48	.45	.42	.42	.39	.37	.34	.33
D	.52	.48	.45	.44	.42	.40	.37	.36
C	.54	.50	.47	.46	.44	.42	.38	.37
B	.57	.53	.51	.48	.46	.44	.40	.39
A	.58	.55	.53	.50	.48	.46	.41	.40

Computed by Eng. Dept. G. E. Co. from E.T.L. test.



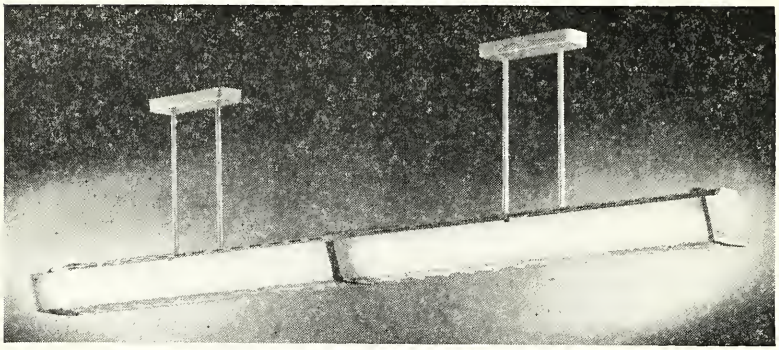
CATALOG SPECIFICATIONS

Catalog No.	Number of Lamps	Std. Susp.	Description	Stand. Wt. Pkd.	Stand. Wt. Unpkd.	Pkg. Quan.
GRL-248-B	2-40-W	4⅛″	Body with Louvers and Plastic Side Panels	22	17	1
GR-248-B	2-40-W	4⅛″	Body without Louvers wit Plastic Side Panels	20	15	1
20		½″	On Ceiling Strap Assembly	1	1	*
21		½″	On Ceiling Outlet Box Cover Assembly	1	1	*
22		20″	Double Stem and Canopy Assembly	3	2	1
23		4″	Ceiling Unit Canopy Assembly	2	1	1
24		20″	Single Stem and Canopy Assembly	2	1	1
25			Set of 2 End Caps, etc. "Ends of Run" Assembly	4	3	1
16			Canopy Extn. for No. 24 to House Canopy Switch	½	½	*
26			Set of 2 Plastic Side Panels	4	3	*
27			Set of 2 Glass Side Panels	5	4	*
29			Set of 2 Topplate Reflectors Not Pierced	4	3	*
30			Set of 2 Pierced Topplate Reflectors	4	3	*

*Direct Shipment Packaging.

THE F. W. WAKEFIELD BRASS COMPANY

Over-All Lighting by Wakefield, Vermilion, Ohio



No. 2B-448-W Suspension Type BEACON

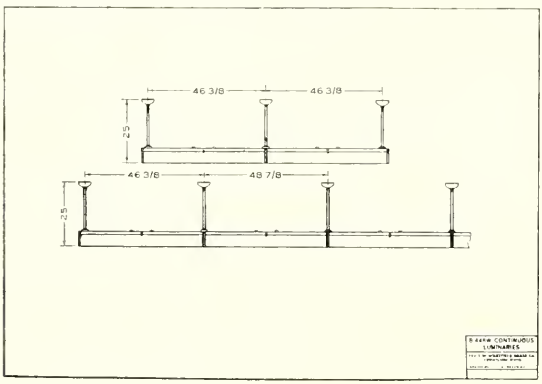
THE BEACON

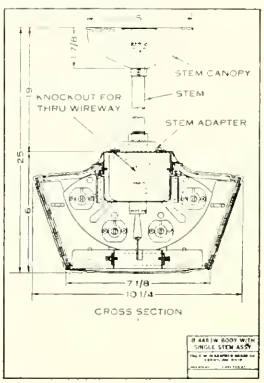
The BEACON is made in 4′ Suspension Types and 4′ Ceiling Types. Both types are available for installation in continuous runs as they may be interconnected. The BEACON is shielded with ribbed etched glass and louvers. Four 40W fluorescent lamps are used in each 4′ section.

Catalog No.	Number of Lamps	Overall Susp.	Description	Standard Weight		Package Quantity
				Packed	Unpacked	
B-4483-W	4—40W	6½″	Ceiling Type	43	36	1
B-448-W	4—40W	25″	Suspension Type	42½	36	1

When ordering continuous units for a specific installation, the number of units in a run should be indicated by a numerical prefix to the catalog number, for example, No. 6-B-448-W, etc. Single stems (Catalog No. 10) for continuous mounting are available.

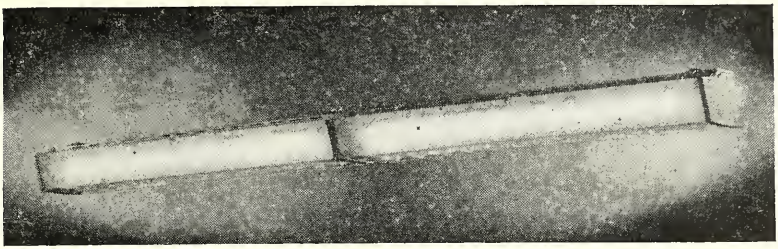
Catalog No.	LUMINAIRE Lamps	M.F.	Average Fcs. In Service	SQUARE FEET PER LUMINAIRE Large Room Width 4 times height		Medium Room Width 2 times height		Small Room Width equals height	
				Light Finish	Medium Finish	Light Finish	Medium Finish	Light Finish	Medium Finish
B-448-W	Four 40-Watt White Mazda F	.70	30	98	82	82	71	65	53
			40	74	62	62	53	48	40
			50	59	49	49	42	39	32
			60	49	41	41	35	32	26





THE F. W. WAKEFIELD BRASS COMPANY

Over-All Lighting by Wakefield, Vermilion, Ohio



No. 2B-4483-W Ceiling Type BEACON

COMPUTATIONS

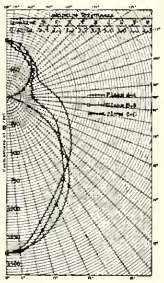
The lamp lumens required to light a room are computed from the following formulas:

$$\text{Lamp Lumens Required} = \frac{\text{Footcandles} \times \text{Area of Room}}{\text{Utilization Factor} \times \text{Maintenance Factor}}$$

$$\text{Lamp Lumens per Luminaire} = \frac{\text{Total Lumens Required}}{\text{Number of Luminaires to be Installed}}$$

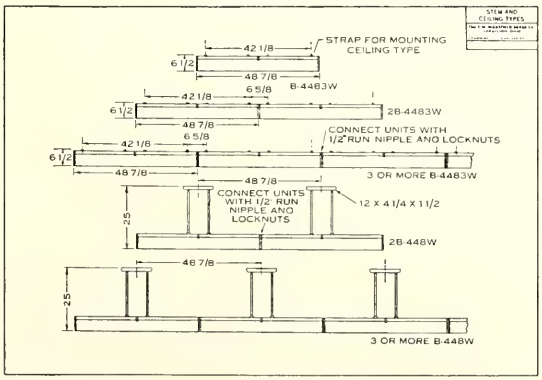
PHOTOMETRIC CHART

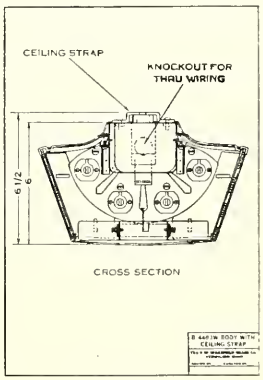
Distribution curve resulting from tests of BEACON by Electrical Testing Laboratories.



MF = 0.70	Ceiling	75%			50%			30%	
	Walls	50%	30%	10%	50%	30%	10%	30%	10%
	Room Index	Utilization Factors							
↑	J	.24	.20	.18	.22	.19	.17	.18	.16
	I	.30	.26	.24	.27	.24	.22	.23	.21
22	H	.33	.29	.27	.30	.27	.26	.26	.24
—	G	.36	.33	.30	.33	.30	.28	.28	.27
45	F	.39	.35	.32	.35	.32	.30	.30	.28
	E	.42	.39	.36	.38	.36	.33	.33	.31
	D	.45	.42	.39	.41	.38	.36	.36	.34
	C	.48	.44	.41	.43	.40	.38	.37	.35
	B	.50	.47	.44	.45	.42	.41	.39	.38
↓	A	.52	.49	.46	.47	.44	.42	.41	.39

Computed by Eng. Dept. G. E. Co. from E.T.L. tests.





THE F. W. WAKEFIELD BRASS COMPANY

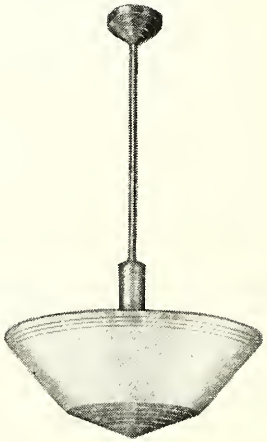
Over-All Lighting by Wakefield, Vermilion, Ohio

THE COMMODORE

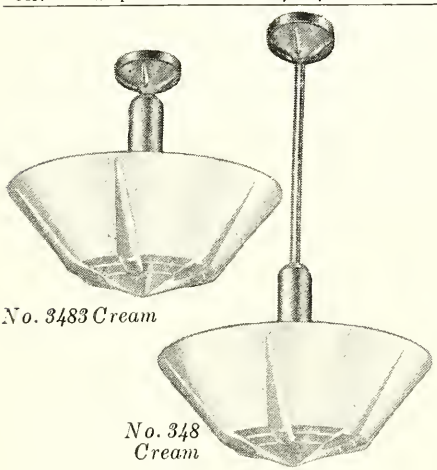
The full line of COMMODORE units with Plaskon reflectors embrace wattages from 200 to 1,000. Nos. 265, 369, 763 and 106 are patterned after each other so that an installation requiring units of various size lamps and reflectors will conform in appearance. Hangers are made from aluminum with satin finish. Reflectors vary in diameter from 15″ to 26″.

WATTAGE, COLOR AND DIMENSION DATA

Cat. No.	Wattage	Color	Dia. Reflector, inches	Socket	Length Overall, inches	Standard Package Weight Lb.	Standard Package Quan.
265	200-300	White	15	Med.	28	24	4
369	300-500	White	19	Mog.	34	8½	1
763	750	White	23	Mog.	44	40	4
106	750-1000	White	26	Mog.	48	55	4
3483	300-500	Cream	18	Mog.	18	8	1
348	300-500	Cream	18	Mog.	34	8½	1
3487	Lamp Shield for No. 369, 348, or 3483					6	12



No. 763-White



No. 3483 Cream

No. 348 Cream

SQUARE FEET PER LUMINAIRE

Catalog Number	Lamp	M. F.	Ave. Fcs. In Service	Large Room Width 4 times height		Medium Room Width 2 times height		Small Room Width equals height	
				Light Finish	Medium Finish	Light Finish	Medium Finish	Light Finish	Finish Medium
369	500-W I.F.	.65	20	133	86	99	64	74	46
			30	97	63	76	46	53	31
			40	73	47	57	35	40	23
			50	58	38	46	28	32	19
348	500-W I.F.	.65	20	136	88	101	66	76	48
			30	100	65	78	48	55	33
			40	75	49	59	36	41	24
			50	60	39	47	29	33	20

WATTAGE, COLOR AND DIMENSION DATA

Catalog Number	Diameter Reflector	Lamp Used	Color	Surface Brightness Candlepower per Sq. In. Min.	Surface Brightness Candlepower per Sq. In. Max.	Distribution of Luminaire Output Downward	Distribution of Luminaire Output Upward	Overall Efficiency	Classification
265	15″	300 W-IF	White	0.4	1.8	12.5%	71.0%	83.0%	Semi-indirect
*348	18″	500 W-IF	Cream	0.5	1.6	10.0%	70.0%	80.0%	Semi-indirect
348	18″	500 W-IF	Cream	0.5	1.4	8.0%	75.0%	83.0%	Indirect
369	19″	500 W-IF	White	0.3	0.8	6.5%	75.0%	81.5%	Indirect
763	23″	750 W-IF	White	0.2	1.0	5.5%	73.5%	79.0%	Indirect
106	26″	1000 W-IF	White	0.1	0.6	3.5%	69.0%	72.5%	Indirect

* Tested with Lamp Shield No. 3487.

Westinghouse Electric Corporation

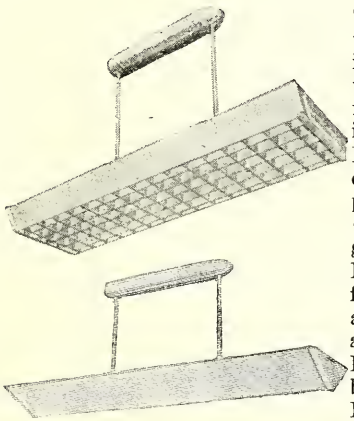
PLANTS IN 25 CITIES — OFFICES EVERYWHERE

LIGHTING DIVISION · EDGEWATER PARK · CLEVELAND, OHIO

COMMERCIAL FLUORESCENT LIGHTING

Westinghouse manufactures a complete line of fluorescent lighting units to meet office, school, store, drafting room or other commercial interior requirements. In addition, lighting and lamp specialists are available through each Westinghouse sales office to consult with you on your lighting problems. Only part of the Westinghouse line is shown here. See Catalog 61-030 for complete information.

LW-80 and LW-160 Fluorescent Luminaires



Types LW-160 and LW-80 Luminaires are designed to provide efficient direct-indirect fluorescent illumination. They are for individual or continuous strip application, ceiling or suspension mounting. Distribution of ceiling mounted unit is semi-direct.

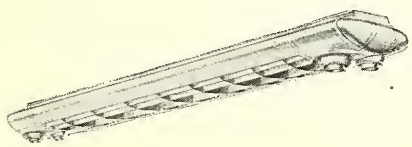
Body assembly consists of rugged sheet metal chassis, decorative steel end covers and glass panels. Side panels are of ribbed diffusing glass. (Bottom of LW-160 may be either clear ribbed glass or louvers.)

Luminaires are furnished completely wired, ready for connection to line leads. Twin stem hangers are provided with sufficient wire to connect to line and to luminaire.

Luminaire body, twin stem hanger, and ceiling brackets are finished in baked white enamel. Ballast case is finished in light gray baked enamel.

CS-160 and CS-200 Fluorescent Luminaires

(The "Merchandiser," with 2SS-150 Swiveling Spotlights)



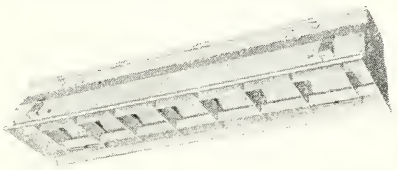
Designed for complete store lighting installations, the fluorescent section of the Westinghouse Merchandiser is available in two styles and two sizes (1) for surface mounting—CS-160, for four 40-watt fluorescent lamps, and CS-200, for two 100-watt fluorescent lamps; (2) for pendant mounting—CP-160, for four 40-watt lamps, and CP-200, for two 100-watt lamps. Housing provides wireway when units are mounted end-to-end, with knockouts at both ends of each unit to permit a continuous run of the feed wires. Luminaires have louvered bottom.

The Swiveling Spotlight (2SS-150) consists of two individually-operated lampholding assemblies, to accommodate two 150-watt, PAR-38, pre-focused, sealed-beam incandescent lamps, available in spot or flood type distribution. Swiveling mechanism will allow up to 35° adjustment from vertical, with a 345° horizontal rotation. Friction clamps hold lamp-holders in position; no tools are necessary to move lamp to new position.

Two end caps are required for each individually-mounted or for each continuous strip.

TR-40, 80 and 100 Fluorescent Luminaires

(For Troffer Installations)



Westinghouse "Troffer" Luminaires are designed for recessing in standard accoustical ceilings or in any false ceiling in which a suitable wood or metal ground has been provided. Available for use with one or two 40-watt or one 100-watt fluorescent lamp, Troffers can be equipped with louvers, cross baffles or glass door.

The basic Troffer unit consists of a one-piece hood and side reflectors, an inner reflector on which the lamp operating auxiliaries are mounted, connector and sheilding accessory. End plates, connectors, louvers and mounting accessories are ordered as separate items.

Simplified maintenance is provided by hinged construction of inner reflector and or louver, so that all parts are accessible without removal or hardware or loose parts.

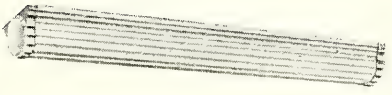
CL-80 and CL-120 Fluorescent Luminaires



Types CL-80 and CL-120 luminaires for two or three 40-watt fluorescent lamps respectively, are designed to provide semi-direct illumination from surface mounted continuous strips or individual units.

Body assembly consists of sheet steel housing with knockouts for conduit, screws and hangers. Reflector is white enameled steel. High power factor ballasts are furnished. Cover has a steel frame, decorated zinc base die cast ends. It hinges open for cleaning or lamp replacement. Luminaire is completely wired.

CL-40 Fluorescent Luminaires



Types CL-40 luminaires are especially designed for continuous strip general commercial lighting installations. Individual units can also be supplied.

Reflector is V-shaped white enameled steel. Glass cover is one-piece, semi-cylindrical, fluted monax glass. Zinc alloy die cast end caps support glass cover. High power factor ballast is furnished. Ornamental channel acts as wireway and support for necessary parts. Luminaires taking 40-watt fluorescent lamps, are completely wired. Luminaire may be wired through flexible conduit, rigid conduit, or outlet box.

BL-40 and BL-100 Fluorescent Luminaires



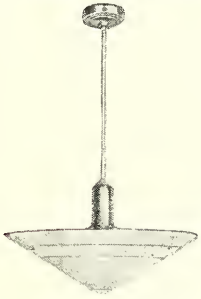
Types BL-40 and BL-100 luminaires are designed for one or two 40-watt or one 100-watt fluorescent lamps, as specified. They are mounted individually or in continuous strips. One-piece body is sheet steel, with knockouts for attaching to ceiling by screws, conduit and outlet box.

High power factor ballast is mounted securely on body. Reflector is V-shaped, finished with white baked-on enamel. Removal of four screws opens reflector for access to electrical parts. End closures for termination of strips or for single units are sheet metal stampings.

COMMERCIAL INCANDESCENT LIGHTING

As with fluorescent fixtures, Westinghouse manufactures a complete line of commercial incandescent luminaires. Available for a lamp range up to 1000 watts, these luminaires are designed for suspension, ceiling or chain mounting. Westinghouse engineers will do more than recommend lighting equipment. They will recommend spacing of fixtures, color of walls and ceilings, and type of finish. To utilize this Westinghouse experience in your modernization or new construction planning, contact your local Westinghouse office. See Catalog 61-030 for complete information.

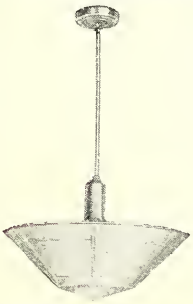
Magnalux Incandescent Luminaire



Magnalux Luminaires are for indirect incandescent lighting, 200, 300, 500, 750 or 1000 watts. Luminaire has drawn steel canopy supported by knurled ring on swivel hickey. Husk, slightly flared at bottom, is shaped to intercept a minimum of light.

Ceiling hanger canopy locks directly to husk. Units are furnished unwired, but with full length leads of proper size. Basin of patented low transmission "Hi-flec" glass provides high inside surface reflection and low exterior surface brightness. Hanger has satin zinc finish and reflector basin is suspended from hanger by three steel rods.

PL-500 Incandescent Luminaires



Type PL-500 luminaire is designed to provide indirect lighting with 300 or 500 watt incandescent lamps. Canopy is of drawn steel, supported by knurled ring on swivel hickey. Stem is one-piece seamless steel tubing, and is easily shortened. Drawn steel husk, slightly flared at bottom, intercepts a minimum of light. Units are furnished unwired but full length leads of proper size are supplied.

Basin is translucent molded plastic material with coloring pigment added to make soft ivory color. Reflecting surface has high reflection factor. Hanger finish is satin-zinc. Reflector basin is suspended from hanger on three steel rods.

Sollite Incandescent Luminaires



Sollite luminaires are designed for general diffuse lighting, 75, 100, 200, 300 and 500 watts. Semi-rigid Suspension, Ceiling and Chain luminaires are available in "Safety Holder" types.

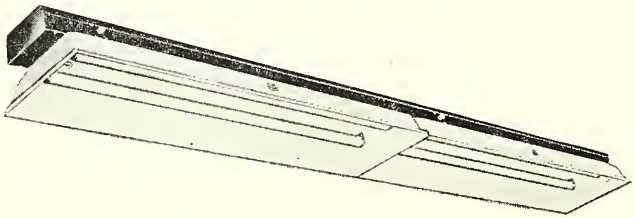
Semi-rigid hanger has drawn-steel canopy for knockout for canopy switch. Steam is one-piece seamless steel tubing. Globe holder is of drawn steel with beaded edge. Rigid strap, conforming to inside of globe fitter, is safety holder support and holder ring keeps globe in place. Globes have flame seared fitter edges. Hanger is finished in statuary bronze. Socket is glazed porcelain. Units are unwired; wire is furnished.

INDUSTRIAL FLUORESCENT LIGHTING

Westinghouse manufactures open and closed end fluorescent luminaires for individual and for continuous strip mounting. Each luminaire consists of a steel hood, porcelain enameled or baked enameled steel reflector and necessary lamp-operating accessories. The hood, with all lamp-holders and starter sockets attached, is formed of heavy gauge sheet steel. High power factor ballasts, twist-turn type lampholders, and wing lock reflector supports permitting easy removal of reflector by turning tension wing locks, are standard equipment. Units are completely wired; unwired units are available on special order. All units shown except FDT are RLM approved with porcelain enameled reflectors. A separate complete line with baked enameled reflectors is also available. See Catalog 61-030 for complete information.

Types FPS-40 and FPS-100 Fluorescent Luminaires

(RLM Closed-end, Continuous Strip)



The complete luminaire consists of a continuous wireway channel with individual reflectors for two or three 40-watt or two 100-watt fluorescent lamps, and necessary lamp operating auxiliaries. The heavy duty channel is provided in unit sections of single and double reflector lengths. Where reflectors are not required in a continuous strip, double sections with single blank channel provide continuous wireway.

Channel assembly is fabricated from sheet steel with ballast, twist-turn type lamp holders and starter sockets mounted as a part of the channel assembly. A "V" groove is formed in each side of the channel to accommodate continuously adjustable slide hangers for messenger cable, rods or ceiling brackets. End plates are available to close the ends of all complete strips and are provided with a $\frac{1}{2}$-inch knockout and switch knockout. Accessory louvers and cover doors are available.

Types FPC-40 and FPC-100 Fluorescent Luminaires

(RLM, Open-End, Continuous Strip)

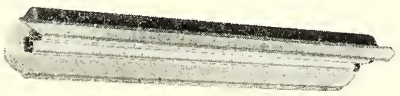


The complete luminaire consists of a continuous wireway channel with individual reflectors for two or three 40-watt or two 100-watt fluorescent lamps, and necessary lamp operating auxiliaries. The heavy duty channel is provided in unit sections of single and double reflector lengths. Where reflectors are not required in a continuous strip, double sections with single blank channel provide continuous wireway.

Channel assembly is fabricated from sheet steel with ballast, twist-turn type lamp holders and starter sockets mounted as a part of the channel assembly. A "V" groove is formed in each side of the channel to accommodate continuously adjustable slide hangers for messenger cable, rods or ceiling brackets. End plates are available to close the ends of all complete strips and are provided with a $\frac{1}{2}$-inch conduit knockout and switch knockout.

Types FPR-40 and FPR-100 Fluorescent Luminaires

(RLM, Open-End, Individually Mounted)



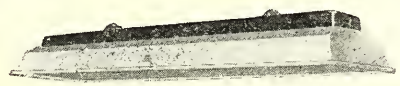
FPR type open-end luminaires consist of a completely wired hood, plus the reflector and necessary auxiliary parts. They are designed for general and supplementary lighting in industrial plants.

FPR-40 is used with two or three 40-watt and FPR-100 with two 100-watt fluorescent lamps.

Hood is of heavy gauge steel, with twist-turn type lamp holders and lamp starters in the hood assembly. Reflector is of heavy gauge steel porcelain enameled. Mounting may be rigid conduit, flexible conduit or chain suspension. Unit is completely wired. Finish of hood is black baked-on enamel. Two-lamp, 40-watt unit (Type FPR-40) is also available with instant start ballast.

Types FP-40 and FP-100 Fluorescent Luminaires

(RLM Closed-End, Individually Mounted)



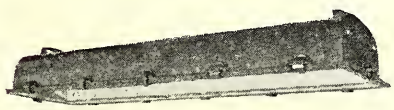
FP type closed end luminaires consists of a completely wired hood, plus reflector and necessary auxiliary parts. They are designed for general and supplementary lighting in industrial plants where precision set-up work is performed.

FP-40 is used with two or three 40-watt and FP-100 with two 100-watt fluorescent amps.

Hood is of heavy gauge steel, with twist-turn type lamp holders and lamp starters in the hood assembly. Reflector is of heavy gauge porcelain enameled steel. Mounting may be rigid conduit, flexible conduit or chain suspension. Unit is completely wired. Finish of hood is black baked-on enamel. Accessory louver and cover doors are available. Two-lamp, 40-watt unit (FPQ-40) is also available with instant start ballast.

FDT-40 Fluorescent Luminaires

(Dust-Tight and Vapor-Tight)



FDT Fluorescent luminaires are designed for locations where combustible coal, coke, carbon or grain dust is present; or for locations requiring vapor-tight units. They are approved for Class II Groups F and G, hazardous locations and also as being Vapor-Tight.

Luminaire consists of a steel housing, hinged cover door, steel reflector, twist-turn lamp holders and auxiliary equipment.

Housing ends are gas-welded to the housing to form a continuous tight, smooth joint. Ballasts are two and three-lamp, lead-lag type with internal compensator and over 90% power factor. Luminaires are completely assembled and wired.

INDUSTRIAL INCANDESCENT AND MERCURY LIGHTING

The prime function of industrial lighting is to provide adequate and comfortable seeing conditions. Regardless of the medium of lighting employed—incandescent, mercury vapor, fluorescent—it must be designed to enable the human eye to do its job accurately, quickly and with a minimum of physical effort.

Industrial incandescent and mercury reflectors are made in several different styles to meet varying conditions. Some are available for both indoor and outdoor use, others are especially adapted to extreme service locations. A few of the many different Westinghouse reflectors are shown. See catalog 61-030 for complete information.



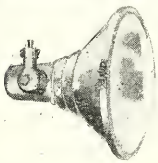
Millite Luminaires

Enclosed Luminaire, designed for heavy duty service in high bay areas. Available for use with incandescent or mercury vapor lamps. Especially adapted to extreme service conditions such as steel mills, foundries, chemical plants. Approved as vapor-tight by Underwriters' Laboratories, Inc. Also weather-proof, can be installed outdoors.



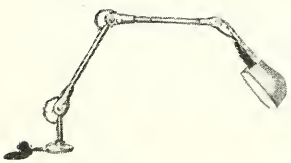
High Bay Luminaires

Used with incandescent or mercury vapor lamps for lighting of high bay areas in foundries, machine shops, power plants, receiving and shipping departments and all similar locations. Cover doors are available.



Concentrators

Designed for lighting horizontal and vertical surfaces from any angle. Provide supplementary lighting where high intensities are required over relatively small areas.



Focalaire

Supplementary local lighting reflectors shield light from worker's eyes and direct maximum intensity on the critical area. Wide variety of base attachments, extension arms and reflector heads available.



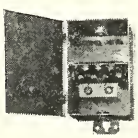
Bin and Stack Luminaires

For proper illumination of library stacks, and storeroom bins. Reflector concentrates light on horizontal and vertical surfaces at bins or shelves with sufficient light on aisle floors.



Type 3 KW Mercury Luminaire

Designed for direct lighting, using one 3000 watt A-H9 Mercury lamp. Recommended for lighting high bay areas with a minimum of 40′ mounting height commonly found in heavy industry plants.



Mercury Lamp Transformers

High reactance auto-transformer, available for 400-watt mercury lamps operating on 115-volt and 230-volt circuits. Capacitor provides high power factor. Also a 3 KW mercury lamp transformer for 230 or 460-volt circuits.

Locklite Reflectors and Hoods

(For 75 to 1500-watt Incandescent Lamps)











LOCKLITE LUMINAIRES are of the two-piece detachable disconnect type, and are designed to reduce installation and maintenance expense to a minimum. Reflector, socket and lamp assembly removable from hood by simple twist-turn without de-energizing line. Locklite finds ready use in all types of industrial applications.

THE COMPLETE LUMINAIRE consists of a hood and a detachable reflector with socket. Hoods are available for either $\frac{1}{2}$-inch or $\frac{3}{4}$-inch conduit or for 4-inch outlet box mounting. Attachment of reflector and hood is accomplished by the three lugs on the reflector engaging in the three slots in the hood. Any reflector fits any hood for complete interchangeability.

THE HOOD consists of a steel housing enclosing a contact receptacle. Three slotted grooves in the hood engage the reflector assembly. A $\frac{1}{4}$-inch square head slotted set screw is provided in the hexagonal cap of the conduit type hood to lock hood to conduit. The outlet box hood is furnished with a steel cover for direct attachment to a standard 4-inch outlet box. The hood is also provided with a water drip-skirt to make the unit weather-proof. The receptacle is front connected, provides straight through wireways and is flexibly mounted on two heavy duty springs assuring positive electrical contact with reflector socket assembly.

REFLECTORS are of highest grade porcelain-enameled steel. The socket in the reflector is a standard keyless type with all metal parts protected. Standard Dome, Deep Bowl, Symmetrical Angle and Glassteel Luminaires conform strictly to the specifications of the RLM Standards Institute and are so labeled.

FINISH—Reflectors are finished with porcelain enamel, white inside and green outside in accordance with the requirements of the RLM Institute. The outside coat of Glassteel Diffuser reflector is white. Locklite hoods are finished green.

GLASSTEEL DIFFUSER GLOBES are available in opal or color correction types. The fitter section of the globes is protected by a suitable metal band.

Other Westinghouse Reflectors and Hoods

Other reflectors and hoods are available—Bayonet Heel, Snap-in, Dust-Tight, and Vapor Tight. Bayonet Heel is available from 75 to 1500 watts; Snap-in from 25 to 200 watts; Vapor Tight from 75 to 500 watts.

Silvered Bowl Diffuser luminaires are also available for highly diffused illumination with 300–500-watt silvered bowl lamps.

The chart indicates what reflector styles are available for each type.

	Standard Dome	Shallow Dome	Concentric	Deep Bowl	Symmetrical Angle	Glassteel Diffuser
Locklite	x	x		x	x	x
Bayonet Heel	x	x		x	x	x
Snap-in	x	x		x	x	
Vapor-Tight	x		x	x	x	
Dust-Tight	x		x	x	x	

Westinghouse FLOOD LIGHTING

INCANDESCENT FLOODLIGHTING

A complete line of ground area, general purpose, heavy duty, and special service floodlights is available, with wide or narrow beam Alzak aluminum reflectors; porcelain enameled reflectors; plain, diffusing or spread type lenses; and a full assortment of mounting arrangements. Many units in addition to those shown here are available. See Catalog 61-030 for complete information.

Ground Area Floodlights



VRC-18—750, 1050, 1500 watts

A durable, weather-tight 18-inch unit for floodlighting sports areas, service stations, car-loading platforms, industrial plants, construction projects and similar installations. The floodlight, arranged for vertical burning of lamps, consists essentially of a mounting bracket, with socket, and a removable reflector assembly. Available for use with mercury vapor or incandescent lamps.



AF-16, AFA-16—750, 1000, 1500 watts

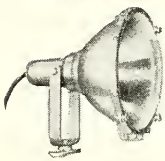
Low-cost, open floodlights, designed to produce a medium or wide beam of high efficiency. They consist essentially of a mounting bracket with socket and a removable bayonet heel porcelain-enameled reflector and integrally attached visor. For the narrower beam spreads, an auxiliary Alzak aluminum reflector is attached inside the porcelain reflector, making the Type AFA-16 unit. Available for use with mercury vapor or incandescent lamps.

General Purpose Floodlights



A-8, A-10, A-14, A-16—100, 200, 300, 500, 750, 1000 watts

Light weight enclosed units, designed for use in business and industrial locations, homes and farms. Typical applications include garage lighting, driveways, roadside stands, decorative lighting of buildings, lawns and gardens, and floodlighting merchandise displays. Floodlights consist essentially of a reflector and lens assembly, socket housing and mounting bracket.



AH-14—300, 500 watts; AH-16—750, 1000 watts

Inexpensive weather-tight general purpose units with hinged cover door for simplified maintenance. They are light weight, yet sturdily designed for indoor and outdoor lighting, of athletic fields, sports center, playgrounds, buildings, industrial sites, service stations, construction projects, etc.

Heavy Duty Floodlights



CAK-12, CAK-14, CAK-16, CAK-20, CAK-24—200, 250, 300, 500, 750, 1000, 1500, 2000 watts

Designed to provide maximum light output at long or short range such as is required for floodlighting railroad yards, industrial and construction projects and protective lighting. They consist essentially of rugged aluminum body, hinged cover door, separate aluminum reflector, trunion type mounting, and a socket assembly. Provision is made for external focusing of lamp.

STREET LIGHTING

The first step in a program of good public safety lighting is the preparation of a sound basic plan which takes into account all traffic conditions peculiar to the locality. Based upon facts uncovered by such a survey, Westinghouse lighting engineers will recommend types of luminaires, lamp sizes, spacing and mounting heights best suited to efficient and economical lighting—all tailored to fit any unusual local conditions.

Universal Metal Head Luminaries

Westinghouse Universal Metal Head Luminaires have been designed to make good street and traffic safety lighting an economically sound investment for every village, town and city. This is the result of standardization of lighting equipment, affording complete flexibility in mounting and wiring arrangements. It also permits speedy and economical conversion from one type of light distribution to another as a community's lighting requirements change. An inexpensive conversion plate is all that is required to change from top to side mounting. Changing from inner to outer wiring, or from outer to inner wiring, also is easy.

Standardization and interchangeability of parts also includes heads, housings, globes or adapters and reflectors.

Poles, Regulators and Control Equipment

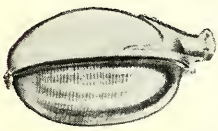
Westinghouse supplies a complete line of poles, cable, regulators and control equipment. For further information, contact the nearest Westinghouse Office.

OV-20 Luminaires

The new OV-20 Luminaires mark another important contribution by Westinghouse to better street lighting . . . at lower costs.

A new optical system consisting of an ellipsoidal shape reflector contour and a shallow, oval-shaped refractor gives more effective light control than has been provided with conventional mercury luminaires.

For Mercury Lamps

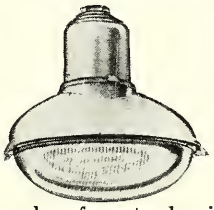


END MOUNTING—The development of the highly efficient short arc or quartz type mercury lamp permits the use of the lamp in a horizontal position. Two such lamps available for use in the OV-20 are the C-H5, 10,000 lumen, and the E-H1, 20,000 lumen.

The ellipsoidal contour is ideal for these mercury lamps, and the horizontal position permits excellent control of vertical light distribution. With the horizontal lamp position, the mercury lamp socket is mounted in the end of the reflector. The unit is attached to a pipe bracket by streamlined aluminum coasting at the end of the oval reflector.

TOP MOUNTING—When it is desirable to use top mounting for mercury lamps, a universal metal head with time-tested bayonet heel is used.

For Incandescent Lamps



The OV-20 optical system is also designed for mounting in standard Westinghouse metal heads for incandescent lamps. These heads are made of cast aluminum and may be obtained with mogul multiple lampholder, with low-voltage series receptacles and lampholders, or with high-voltage porcelain series receptacles and lampholders.

Top of reflector assembly is provided with a neck with bayonet slots for mounting on the pins provided in the head. A mechanical spring arrangement in the neck assembly provides a tight fit between the reflector assembly and the head, eliminating need for gasket. A heat barrier side plate is recommended for all 15,000 lumen or 750-watt incandescent applications.

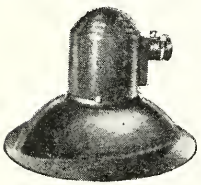
AK-10 Luminaires with Universal Metal Head



Type AK-10 luminaires provide moderate-priced enclosed units for incandescent lamps (2500 to 10,000 lumens) or C-H5 or F-H1 mercury lamps. With the Westinghouse Universal Head and a reflector housing, a wide selection of globes or refractors may be had to produce any desired distribution of light as specified by IES recommended practice. By using an adapter, radial flat reflectors, asymmetric radial flat reflectors, radial bowl reflectors, or asymmetric radial bowl reflectors can be used. Also, the OV-18 reflector, described below, can be used with the same universal metal hood.

OV-18 Luminaires with Universal Metal Head

(For 1000 and 2500 Lumen, 5⅜" Light Center Lamps)



Type OV-18 reflectors have rotated parabolic contour. The flange or skirt is made integral with the reflector, giving the proper shielding or cutoff. The bottom edge of the lamp filament is approximately ⅝" above the lower edge of the reflector, giving an absolute cutoff of 85°. This results in reduction of glare.

The contour design reflects approximately 50% more candlepower up and down the street, with the candlepower to the side about equal to present radial wave reflectors, except for the cutoff at 85°. The lamp, located up in the reflector, is given added protection from outside forces.

Application of Lighting by Street Classification

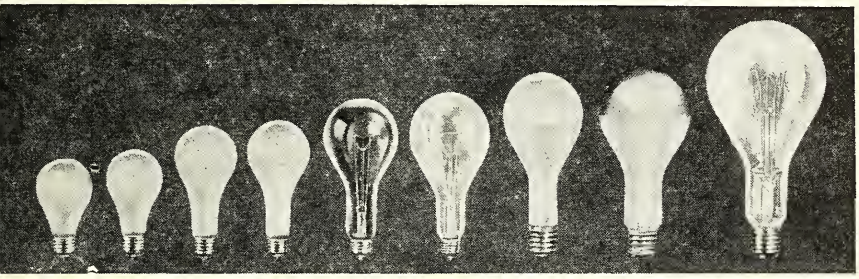
Width of Street	Westinghouse Luminaire	Lamp Size (In Lumens)	Mounting Height (In Feet)	Spacing (In Feet)
1.2 Footcandle—Primary Business Streets – Vehicular Traffic, Heavy – Pedestrian Traffic, Heavy				
80 feet	AK-15 Type IV	15,000	30	110 opposite
60 feet	AK-10 Type IV	10,000	25	100 opposite
50 feet	AK-10 Type IV	10,000	25	110 opposite
1.0 Footcandle—Secondary Business Streets – Vehicular Traffic, Medium – Pedestrian Traffic, Heavy				
70 feet	AK-10 Type IV	10,000	25	110 opposite
50 feet	AK-10 Type IV	10,000	25	65 staggered
40 feet	AK-10 Type IV	10,000	25	75 staggered
.8 Footcandle—Minor Business Streets – Vehicular Traffic, Medium – Pedestrian Traffic, Heavy				
70 feet	AK-10 Type IV	10,000	25	70 staggered
50 feet	AK-10 Type III	10,000	30	80 staggered
40 feet	AK-10 Type III	6,000	25	60 staggered
1.0 Footcandle—Heavy Traffic Streets – Vehicular Traffic, Heavy – Pedestrian Traffic, Medium				
60 feet	AK-10 Type III	10,000	30	60 staggered
40 feet	AK-10 Type II	10,000	30	90 staggered
.8 Footcaddle—Medium Traffic Thoroughfare – Vehicular Traffic, Medium – Pedestrian Traffic, Medium				
60 feet	AK-10 Type III	10,000	30	75 staggered
40 feet	AK-10 Type II	10,000	30	110 staggered
30 feet	AK-10 Type II	6,000	25	75 staggered
.6 Footcandle—Light Traffic Thoroughfare – Vehicular Traffic, Medium – Pedestrian Traffic, Light				
50 feet	AK-10 Type II	10,000	30	125 staggered
40 feet	AK-10 Type II	6,000	25	140 staggered
30 feet	AK-10 Type II	6,000	25	100 staggered

Westinghouse

Bloomfield, New Jersey

Belleville, N. J. Trenton, N. J. Fairmont, W. Va.

INCANDESCENT LAMPS



Watts	40	60	100	150	200	300	300	500	1000
Finish	Inside Frosted			Daylight Inside Frosted	Daylight Clear	Clear	White Bowl	Silvered Bowl	Clear

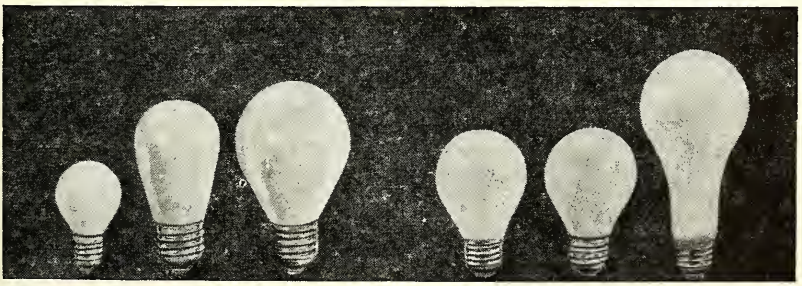
INSIDE FROSTED. These lamps are designed to meet the widest variety of requirements for general purpose illumination. Inside frosted finish reduces glare, provides a softer, more diffused light and distributes it over a wide area. Light output rating same as for clear glass. 15 to 1000 watts, 115, 120, 125 volts.

CLEAR. Sizes from 150 to 1500 watts; 115, 120, 125 volts. For use where light must be controlled by a reflector, as in certain industrial and commercial lighting fixtures. This application is not to be confused with use of clear lamps in spotlighting, projection and certain types of floodlighting for which there are available lamps especially designed for the service.

WHITE BOWL. Designed for use in open type reflectors to minimize glare and soften shadows. The bowl area of these lamps is covered with a translucent milk-white coating which shields the direct rays of the filament from the eyes. 150, 200, 300 and 500 watt sizes; 115, 120, 125 volts.

SILVERED BOWL. Designed particularly for indirect lighting from specially designed fixtures or built-in coffers. The coating of mirror silver on the bowl shields the direct rays of the filament and forms a highly efficient reflecting surface. Burn base up only. Sizes 60 to 500 watts; 115, 120, 125 volts.

DAYLIGHT. The bulbs of these lamps are made of a special blue glass to produce light approximating that of average daylight quality. Inside frosted or clear finish available in all sizes from 60 to 500 watts; 115, 120, 125 volts.



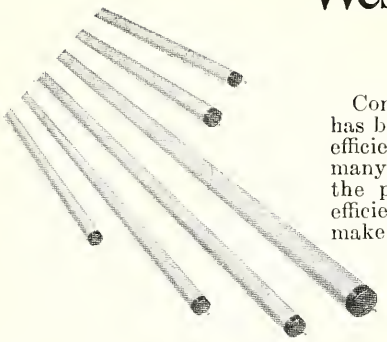
Watts	10	10	25	50	50	100
Finish	White	Inside Color	Natural Color	Vibration Service	Rough Service	

INDICATOR. Red, Green and Blue lamps, inside colored finish and natural colored bulbs. 10 and 25 watts. Other lamps: 5 watt clear; 7½ watt white; 7 watt clear or white; 10 watt clear, (115, 120, 125 volts).

VIBRATION. These lamps are specially designed and constructed to withstand vibration such as on high speed machinery. They are not suitable for use on portable extension cords. 50 watts, inside frosted. 115, 120, 125 volts.

ROUGH SERVICE. Built to withstand the severe jars and shocks such as found in extension cord use in garages and other similar applications. Available in 50 and 100 watt sizes with inside frosted finish. 115, 120, 125 volts.

Westinghouse



FLUORESCENT LAMPS

Continuing development of the fluorescent lamp has brought marked improvement in the all-around efficiency of this form of lighting. Its shape plus the many available sizes lends itself to modern design and the provision of even distribution of light. The efficiency and soft quality of fluorescent lighting make it desirable for use in factory, home or office.

Westinghouse makes a complete line of standard fluorescent lamps from six watts 9″ long to 100 watts 60″ long. The sizes shown in the table below are most widely used.

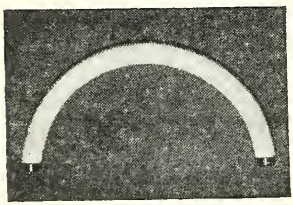
DATA ON WESTINGHOUSE FLUORESCENT LAMPS

Watts	Bulb Diameter	Nominal Overall Length	Rated Initial Lumens White	Daylight	4500 White	Soft White
15	T-8 (1″)	18″	615	585	600	480
15	T-12 (1½″)	18″	600	540	570	465
20	T-12 (1½″)	24″	920	800	860	700
30	T-8 (1″)	36″	1470	1350	1380	1170
40	T-12 (1½″)	48″	2320	1920	2100	1720
100	T-17 (2⅛″)	60″	4200	3900	4000	3300

SLIMLINE LAMPS

Slimline lamps, longer and more slender than standard fluorescent lamps, give an almost continuous line of light when mounted end to end. Slimline lighting gives instant start operation and is suitable for use at various levels of output and brightness. Lengths: 42″, 64″, 72″, 96″ including lampholders.

Lamp	Base	Rated Initial Lumens 4500 White
16W	42″ T-6	880
25W		1320
33W		1620
24W	64″ T-6	1370
39W		2150
51W		2600
22W	72″ T-8	1340
38W		2250
51W		2850
29W	96″ T-8	1800
51W		3050
69W		3950



CIRCLARC LAMPS

The Circlarc lamp is a curved fluorescent lamp made in the form of a half circle 12″ in diameter. It can be used singly or in multiple arrangements to provide a wide flexibility of application. Two of these lamps can be combined to form a complete circle where desired.

This 18 watt lamp may be operated directly from 110–125 volt 60 cycle alternating current circuits with a small low cost choke as a ballast.



Westinghouse

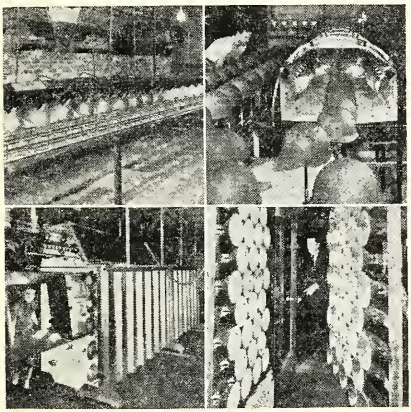
MERCURY VAPOR LAMPS

The high output and long life of these lamps recommends their use for highbay mounting where areas are large and a high degree of color discrimination is not required.

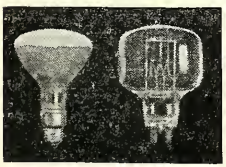
Improved street, general and floodlighting and new applications in black light, photochemical, blueprinting, searchlight and projection uses have resulted from the continuing development of this type. Type shown is available for base up (A-H1) or base down (B-H1) burning.

WESTINGHOUSE MERCURY VAPOR LAMPS, TYPE H

Nominal Watts	Type or Ordering Number	Bulb	Base	Approx. Lumens (Initial)	Max. Overall Length	Burning Position
	A-H1	T-16 Clear	Mogul Screw	16,000	13″	Base Up
400	B-H1	T-16 Clear	Mogul Screw	16,000	13″	Base Down



Industrial installations of infrared lamps indicate variety of applications to which they are suited.



Left—R-40 and T-40 Bulb Lamps

Westinghouse

INDUSTRIAL INFARED LAMPS

Speed up many Drying, Baking and Heating jobs

Due to low cost, speed, simplicity of installation and general suitability, infrared radiation is being used for a multiplicity of industrial drying and heating applications.

Both internal-reflector and non-reflector types of industrial infrared lamps are available in a variety of wattages for use on 110–125 volt circuits. Of these, the 250 and 375 watt R-40 bulb reflector types are by far the most popular.

WESTINGHOUSE INDUSTRIAL—INFRARED LAMPS

Watts	Volts	Bulb	Base	Nominal Bulb Diameter Inches	Maximum Overall Length Inches
250	110–125	R-40	Medium Skirted	5	7¼
375	110–125	R-40	Medium Skirted	5	7¼
500	110–125	T-40	Medium Bipost	5	7¼
1000	110–125	T-40	Medium Bipost	5	7¼

Westinghouse

REFLECTOR and PROJECTOR LAMPS



Self-contained, with sealed-in reflector. Projector lamps (right) resist weather for outdoors, safety lighting, general duty. Spot or flood. 150 watts. Reflector lamps (left) for displays, garage work. Indoors only. Spot or flood. 150 or 300 watts.

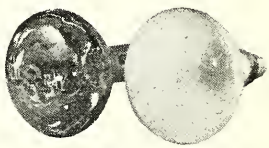


SUN LAMPS and HEAT LAMPS

The small, light, self-contained reflector units that comprise these lamps make them particularly practical for use in the home. Sun lamp provides ultraviolet radiations such as are found in natural sunlight.

The heat lamp is an inexpensive source of penetrating infrared heat rays. It is available with either the usual type glass or the Pyrex glass bulb—the latter, known as the Heat Ray lamp, is resistant to breakage on contact with water. It is colored red to reduce glare and make identification easy.

Sun lamp operates on 115–125 volts, 60 cycle a-c; heat lamps on 110–125 volt, a-c or d-c.



STERILAMPS

for Destroying Harmful Bacteria in the Air



Sterilamps provide selected ultraviolet radiation for killing airborne or surface bacteria, virus and mold spores. Used in industry to prevent spoilage and maintain the quality and purity of products; in room units, schools, offices and public places to minimize contamination. The line includes eleven wattages and sizes, hot cathode as well as cold. Lamps operate on 110–120 volt, 60 cycle a-c.



WHEELER REFLECTOR COMPANY

275 Congress Street, Boston 10, Mass.

New York Office - 120 West 18th Street — Representatives in principal cities

Manufacturers of Industrial Lighting Equipment since 1881

Products

A complete line of Incandescent Reflectors & Accessories.
Industrial Type Fluorescent Fixtures.
Street Lighting Fixtures.

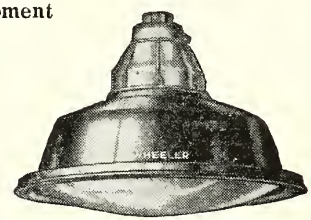
Trade Names

Durex Reflectors—Duratach Reflectors
Vapolux Fixtures—Meteor Floodlights
Isolux Sign Reflectors

Incandescent Lighting Equipment

The Wheeler Line of Incandescent Reflectors includes fixtures for general lighting purposes, floodlighting, sign lighting, vaporproof installations and for many other types of illumination.

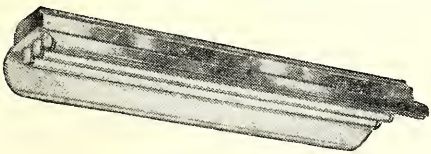
Practically all lines of equipment, with the exception of Alzak Aluminum types of fixtures, are constructed from heavy gauge steel and finished in porcelain enamel. Canopies are available for all standard types of mounting.



"Class II-G" Vapolux Unit

The Vapolux type of unit shown in photograph is approved for use in Class II-G Hazardous Locations. This type of fixture, which is completely dust-tight, was developed for use in locations where fixtures are exposed to dust, vapor, smoke and fumes.

Heavy Duty Industrial Fluorescent Fixtures



3-40 Watt Open End Fixture

Wheeler Fluorescent Fixtures are designed and manufactured to conform with specifications and standards of RLM Standards Institute.

All fixtures are constructed from 20 gauge steel. Reflectors are porcelain enamelled inside and outside. Wiring channels are finished in baked synthetic enamel to blend with reflectors.

Reflectors are demountable from wiring channels for ease in installation and maintenance.

Fixtures are available for individual or continuous runs and can be furnished with open or closed end reflectors in sizes to take 2–40, 3–40 or 2–100 watt lamps.

"Series II" Dust-Tight Fluorescent Fixtures

This type of fixtures is listed by Underwriters' Laboratories for use in Class II, "Group G and F" and Class III and IV Hazardous Locations.

Units are completely vapor-tight and can also be used to protect lamps, sockets and reflecting surfaces in locations where exposed to moisture or non-combustible dust.



"Series II' Fixture

The entire outer body of the reflector, including its closed ends, is porcelain enameled in one piece. All sockets and lamp operating equipment are mounted on a wiring channel which is installed through the mouth of the reflector.

Fixture is made in two and three lamp 40-watt styles and is available with double-thick plain clear, water white place glass or tempered, clear safety plate glass hinged dust-tight covers.

Units are furnished with two flat flanges, spaced on 36″ centers, tapped ½″ standard, ¾″ if specified.

For complete information, write for catalogs.

M-183

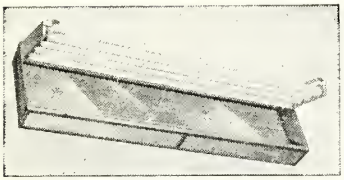
R. & W. WILEY, INC.

Dearborn at Bridge St., Buffalo 7, New York

Engineering Sales Representatives in Important Cities

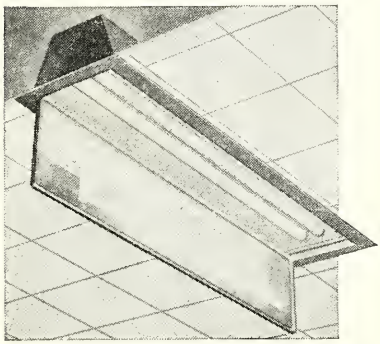
Products: WILEY Commercial, Troffers and Industrial Fluorescent Fixtures

E. T. L. Certified *Underwriters Approved*



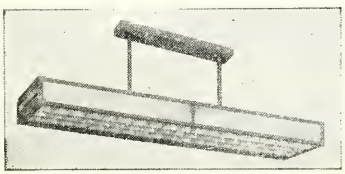
WILEY E-Z SERVICER
(Patent Pending)

All Wiley Troffers, Commercials or Industrials with glass or louvers have the E-Z Servicer feature. One man, without tools, can service or clean fixtures in a matter of minutes. Simply lift one side, move sideways and drop open. Shielding assembly may remain attached when open or lifted off for easier cleaning, if preferred. The E-Z Servicer assures top efficiency and low maintenance costs.



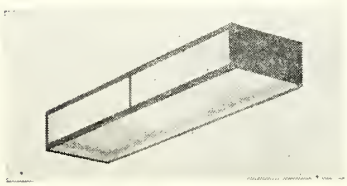
WILEY RECESSED TROFFER
with E-Z Servicer

The Wiley Troffer requires only $6\frac{3}{4}''$ headroom. Detachable end flanges and couplers permit a stock unit being used individually or in continuous rows. Open, louvered or glass bottoms are interchangeable. J-M or flat flanges. Stock units in 2, 3 or 4 40-watt lamps—other sizes on special order. Starter or Instant Start (HPF).



WILEY NIAGARA FLEUR-O-LIERS
with E-Z Servicer

Modern design of attractive simplicity with translucent side panels. Louvers or glass bottoms are interchangeable. Companion models for 2, 3, 4 or 6 40-watt lamps. Starter or Instant Start Ballasts (HPF). Suspended or flush mounting. Individual or continuous rows.

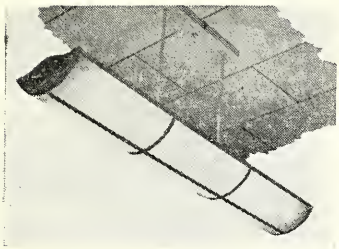


WILEY NIAGARA BEAM
with E-Z Servicer

A flush-to-ceiling unit with translucent side panels is designed to simulate an illuminated ceiling beam. Louvers or glass bottoms are interchangeable. 2, 3 or 4 40-watt lamps. Starter or Instant Start Ballasts (HPF). Individual or continuous rows.

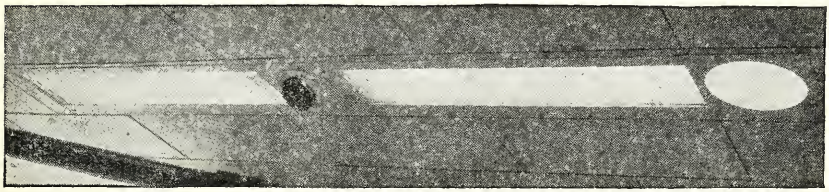
R. W. WILEY, INC.

WILEY ERIE Indirect—Direct Unit
with E-Z Servicer



The Wiley Erie is a suspension unit employing 2 100-watt lamps. 80–85% of light is directed to the ceiling. The white translucent curved sides are of the approximate brightness of the ceiling, producing a completely diffused illumination. Individual or continuous row installation.

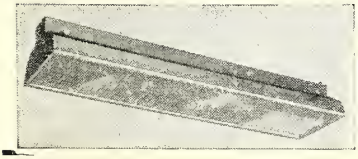
WILEY SPOTS

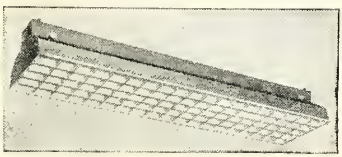


Wiley Spots are used to "high-light" featured articles and to blend incandescent and fluorescent color values.
They may be used individually or combined with Wiley Niagaras, Beams or Troffers; between units, at ends, corners, crosses or Tee forms, permitting unusual ceiling patterns.

Adjustable type (60° on all directions) uses G E (Spot or Flood) PAR 38 150-watt or R 40 150 or 300-watt or equivalent. Louver or color screen optional. Fixed Lens Type with Corning Lenslite No. 545720 wide angle round lens (60°); uses G E PS-25 150-watt, PS-30 200-watt or PS-34 300-watt or equivalent.

WILEY INDUSTRIAL FLUORESCENTS
with E-Z Servicer





High quality Industrial units. Channel ends protect lampholders from breakage and prevent spreading. Reflectors easily removed making all wiring accessible. Starters accessible without removing lamps. Available with open or closed ends and louvered or glass bottoms (E-Z Servicer), for individual or continuous row installation; 2, 3 or 4 40-watt lamps; with starter or instant start (HPF) and 2 100 watt in starter type (HPF).

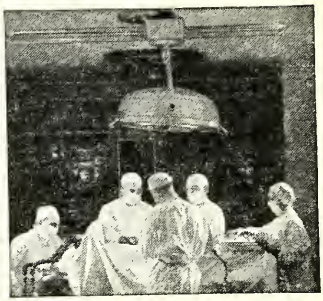
Construction details, engineering data, candle power distribution, charts and photographs of installations are available from District Sales Engineers or Factory.

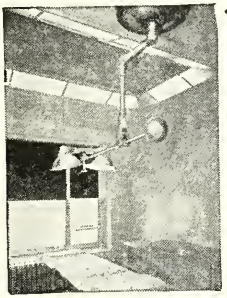
WILMOT CASTLE COMPANY

1191 University Ave., Rochester 7, New York

HOSPITAL LIGHTS MEDICAL LIGHTS DENTAL LIGHTS

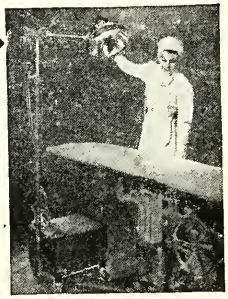
Castle No. 12 Operating Room Light for Major Surgery. Mounted on a 6-foot rotating track, lamphead can be positioned at any angle at any point in a 6-foot circle. Depth of focus eliminates vertical adjustment. →

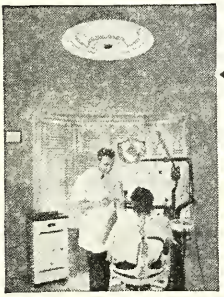




← *Castle No. 17-0 Twinlite for Major Surgery.* Two self-focusing reflectors provide light at many angles to penetrate the deepest incision. Distance between lampheads causes further angulation of light rays for good shadow reduction.

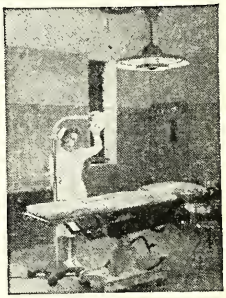
Castle No. 30 Emergency Spotlight. → Eliminates the dangers of light interruption from power failure due to any cause. Special "Multi-Rate" charger keeps battery charged during normal use; restores full charge in 4–6 hours without removal of battery.





← *Castle Balanced Illumination in Dentistry.* With high intensity intra-oral lighting it is essential that a high level of illumination be maintained around the chair and other areas where the dentist is working in the office. The Castle "G-V" (General Vision) Light is particularly designed to balance with good intra-oral lights. (The PanoVision and Tru-Vision Lights.)

Castle Balanced Illumination in the Examination Room. → The "G-V" (General Vision) Light, adaptable to high and low ceilings, minimizes contrasts and shadows. The Castle No. 46 Spotlight, for intra-cavity work, raises to 75″ and lowers to 48″. Lamphead can be tilted and rotated to any angle.



Castle "Quality" Light. All Castle Lights are equipped with a special Aklo glass filter to prevent more than 1 or 2° temperature rise. Filter also produces a color of the following trilinear coordinates: x.389; y.410; z.201. Ratio between the 670 line and 700 line is not less than .9, assuring an absence of a greenish cast in the light beam, which is common to ordinary heat-absorbing glasses.

Reflecting surface of all Castle reflectors is constructed in 28 steps to provide multiple angulation of light beams for increased shadow reduction.



VISION IN SURGERY

VISION IN DENTISTRY



CASTLE LIGHTS AND STERILIZERS

Send for your free copy of these informative booklets:

* Physical and Photometric Data from Test in Company Laboratory.

THE WIREMOLD COMPANY

Hartford 10, Connecticut

Sales Representatives in
Atlanta, Chicago, Dallas, Detroit, Elmira, N. Y., Los Angeles,
Minneapolis, New York, Philadelphia, Pittsburgh, San Francisco, Seattle.

Manufacturers of Surface Metal Raceway Wiring Systems and Fittings; "Plugmold" Plug-in-anywhere Multi-Outlet Systems; "Pancake" Overfloor Wiring Systems; Fluorescent Lighting Equipment; "Wireduct" Non-Metallic Flexible Conduit.

WIREMOLD Raceways and Fittings

Ten complete interconnectable wiring systems with installation fittings for electric light and power or telephone wiring, providing safe, permanent installation "from panel box to outlets." Raceways and fittings are listed by the Underwriters' Laboratories, Inc., The Factory Mutual Laboratories and Canadian Standards Association. Complete revised Catalog and Wiring Guide on request.



WIRE CAPACITIES—WIREMOLD RACEWAYS

Cat. No.	Type R or RH Single Conductor							Type T or RU Single Conductor						
	#6	#8	#10	#12	#14	#16	#18	#6	#8	#10	#12	#14	#16	#18
200	—	—	—	2	2	4	4	—	—	—	2	2	6	8
500	—	—	2	3	4	6	6	—	2	4	6	6	10	10
700	—	2	3	4	5	10	10	—	3	6	8	8	16	18
1000	4	5	6	10	10	24	24	5	8	8	10	10	40	50
1100	3	5	8	10	10	24	24	6	10	10	10	10	40	50
1500	—	—	—	4	4	6	8	—	4	4	6	8	10	14
1900	—	—	—	2	2	10	10	—	—	—	2	2	10	10
2100	4	6	10	10	10	24	24	5	8	10	10	10	40	50
*2100	—	—	—	6	6			—	6	8	10	10	—	—
2600	Two 26-pair telephone cables													
3000	8	10	10	10	10	100	100	8	10	10	10	10	100	100
*3000	6	8	10	10	10			8	10	10	10	10	—	—

* With receptacles or devices in place.

WIREMOLD Fluorescent Lighting Equipment

The Wiremold line of fluorescent lighting equipment consists of a series of units based on the use of the regular No. 3000 raceway and consists of several types and lengths to accommodate 15, 20, 30, and 40 Watt lamps.

In addition, the new 21A Series for use with 15 Watt fluorescent lamps has the advantage of an extremely small cross-section (only $1\frac{1}{4}$" wide x $1\frac{15}{16}$" high) and is available in several variations.

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Date Due

Due	Returned	Due	Returned
SEP 29 '65	SEP 19 '65		
DEC 3 '65	JAN 21 '66	NOV 30 1982	
AUG 22 '67	AUG 23 '67	DEC 14 1983	
	MAR 11 '68		
MAR 15 '69	[illegible] '69	OCT 18 1986	OCT 17 [illegible]
MAR 9 '70	MAR 10 '70		
APR [illegible] '70	MAR 13 '70		
APR 1 '70	MAR 12 '71		
JUN 4 '70	JUN 4 '70		
APR 25 '72	APR 25 '72		
MAY 18 '72			
[illegible]	JUN 2 '72		
MAR 12 '73			
MAY 6 '73			
JAN 31 '74	JAN 31 '74		
FEB 21 '74	FEB 21 '74		
MAR 14 '74	MAR 6 '74		
DEC [illegible]	DEC 5 '74		
DEC 10 '76			
DEC 16 '77			
FEB 7 '78	[illegible] '78		
APR 20 '78	APR 2[illegible] '78		
APR [illegible] '78			
MAY 22 '80			

IES lighting handbook; the standard afa
621.32129i C.2
3 1262 02172 0593
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